



## Two-Tier Diagnostics for Evaluating Submicroscopic Representations in Stoichiometry

Muhammad Fath Azzajjad<sup>1\*</sup>, Dewi Satria Ahmar<sup>2</sup>, Ahmad Kadir Kilo<sup>3</sup>

<sup>1</sup>Universitas Sembilanbelas November Kolaka, Kolaka 93567, Indonesia

<sup>2</sup>Universitas Tadulako, Palu 94119, Indonesia

<sup>3</sup>Universitas Negeri Gorontalo, Gorontalo 96554, Indonesia

### Article Info

#### Article history:

Received: 31-12-2025

Revised: 12-01-2026

Accepted: 20-01-2026

Available online: 01-02-2026

#### Keywords:

Submicroscopic-representation; Stoichiometry; Two-tier-diagnostic; Problem-based-learning; Audiovisual-media

#### \*Corresponding author:

[muhammad.fath86@gmail.com](mailto:muhammad.fath86@gmail.com)

### Abstract

Students must combine symbolic calculations with submicroscopic representations of particles and reaction processes in order to understand stoichiometry, a fundamental concept in chemistry. Nonetheless, prior research indicates that students frequently depend on algorithmic processes without cultivating cohesive particle-level reasoning, leading to enduring misconceptions. In teaching basic chemistry, this representational mismatch continues to be a significant obstacle. Thus, utilizing a two-tier diagnostic method, this study sought to determine how well audiovisual-supported Problem-Based Learning (PBL) improved students' submicroscopic representational abilities in stoichiometry. Thirty-three undergraduate students taking a Basic Chemistry course participated in a quasi-experimental design with a comparison based solely on the posttest. With equal starting ability distributions, participants were split into two groups: a control group ( $n = 17$ ) that received PBL without audiovisual assistance and an experimental group ( $n = 16$ ) that received PBL combined with audiovisual media. A two-tier multiple-choice diagnostic test that evaluated both response correctness and particle-level reasoning was used to gauge the students' submicroscopic comprehension. Descriptive statistics, diagnostic category profiling, and effect size estimation were used to examine the data. According to the findings, the experimental group outperformed the control group in terms of coherent submicroscopic representation and misconception rates. All stoichiometry subtopics showed learning increases, but relational and inferential tasks like particle ratio interpretation and limiting-reactant reasoning showed the strongest results (Cohen's  $d = 1.41$ ). These results emphasize how crucial it is to incorporate diagnostic tests and representationally rich instructional materials in order to foster meaningful learning in chemistry and stoichiometry classes.

**How to Cite:** Azzajjad, M. F., Ahmar, D. S., & Kilo, A. K. (2026). Two-Tier Diagnostics for Evaluating Submicroscopic Representations in Stoichiometry. *Jambura Journal of Educational Chemistry*, 8(1), 64-76. <https://doi.org/10.37905/jiec.v8i1.36488>

## 1. INTRODUCTION

The requirement to coordinate Johnstone's "chemistry triplet" macroscopic phenomena, submicroscopic particle models, and symbolic representations under a high cognitive load is frequently cited as the reason why students struggle in chemistry (Mundy et al., 2023; Ribič & Devetak, 2025). Learners frequently develop fragmented understanding and enduring misconceptions about the meaning of chemical symbols at the particle level when instruction and evaluation prioritize symbolic manipulation (formulas,

equations) without making the particulate level clear (Moreira da Silva & Barroca, 2025; Pugh & Hogarth, 2025; Simanjuntak et al., 2025). This worldwide issue is frequently addressed in professional teaching materials and chemistry education studies, which highlight the triplet as a central reason why chemistry seems "incomprehensible" to many secondary pupils. This challenge is of utmost importance since the flaws in the submicroscopic reasoning that were developed during high school education will not only remain but become even more pronounced at the university level thereby

affecting students' conceptual readiness and their success in the basic chemistry courses of the university.

The issue is made worse in Indonesia by unequal access to representational learning resources and overall poor scientific literacy performance (Laukaityte et al., 2024). Indonesia's PISA 2022 science average, according to the OECD, was 383; this indicates significant difficulties in using scientific concepts and evidence to support arguments at the conclusion of mandatory education (Kemendikbud Ristek, 2023).

Studies conducted in Indonesian classrooms reveal that students' proficiency at the submicroscopic level is usually much lower than at the macroscopic or symbolic levels (Moju et al., 2025; Silva & Sasseron, 2025). For instance, one study found that submicroscopic representation was in a low category (about 18%) in contrast to higher macroscopic and symbolic scores (Alqadri & Munawwarah, 2025; Torres et al., 2025). All of these findings point to the structural necessity of improving submicroscopic reasoning in secondary chemistry education rather than it being a specialized problem.

The two-tier approach in this study clearly assesses the quality and coherence of students' submicroscopic representations by connecting answer correctness to the depth and consistency of particle-level reasoning, in contrast to traditional diagnostic use that only highlights misconceptions. Important research gaps still exist despite the increased interest in diagnostic assessment. Many empirical investigations and assessments in the classroom still place a strong emphasis on algorithmic correctness (calculations, procedures), and they interpret misconceptions as mistakes in final replies rather than as a failure to relate symbols and quantities to particle-level meaning (Atabek-Yigit et al., 2025). Recent research on stoichiometry learning in Indonesia demonstrates that misconceptions frequently occur as a result of students' attention being drawn to algorithms at the expense of conceptual knowledge (Wannomai et al., 2024).

To assess the accuracy of submicroscopic representations included into stoichiometric reasoning, two-tier instruments have been designed for chemical topics, including stoichiometry (Damayanti & Putri, 2025). However, their primary purpose is to identify mistakes in general.

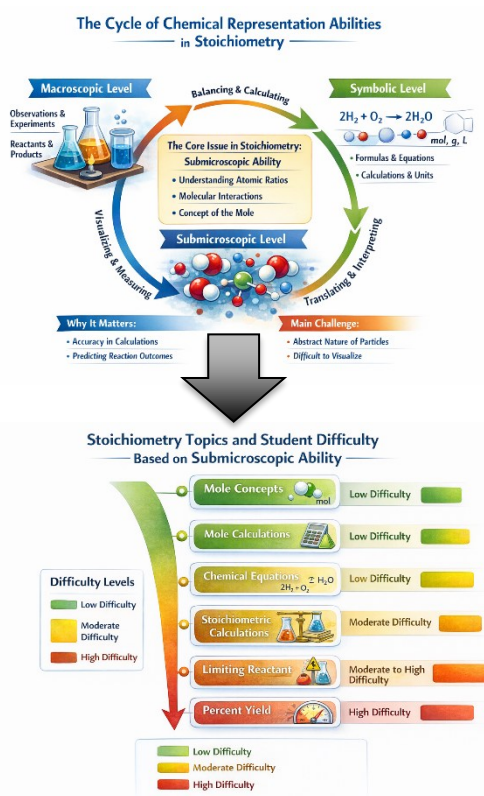


Figure 1. Level of chemical representation in stoichiometry material

By demonstrating that submicroscopic talents act as a conceptual bridge connecting the macroscopic and symbolic levels in stoichiometry, Figure 1 clearly supports the study's central claim. The first diagram highlights that students' ability to understand atomic ratios, molecular interactions, and the idea of moles at the particle level which directly affects the success of balancing, calculation, and translation between representations is the primary challenge in stoichiometry rather than observation or calculation alone. By demonstrating that the level of difficulty of stoichiometry material rises with the increasing demands of submicroscopic representation particularly in the topics of reaction limits and percentage yields, which are consistently categorized as high difficulty levels the second diagram further elucidates the pedagogical implications of this argument. Therefore, these two figures logically support the idea that strengthening submicroscopic representations through suitable instructional and diagnostic strategies developed in this study must be the systematic goal of improving stoichiometry learning, both in secondary and higher education.

Submicroscopic representational competency serves as a conceptual engine that makes chemical quantities understandable, hence research into it is crucial. More specifically, stoichiometry is more than just "math in chemistry"; it is a detailed explanation of conservation and proportionality, or the relationship between particle counts (moles) in reactants and products. The triplet framework contends that flexible translation between macroscopic observations, particulate models, and symbols is essential for a strong understanding of chemistry; in the absence of the submicroscopic bridge, students may correctly manipulate equations while maintaining inaccurate mental models of matter and reaction processes (de Miranda & da Silva Freire, 2025).

For secondary pupils, stoichiometry also focuses on various learning challenges. The mole notion, interpreting coefficients and subscripts, conceptualizing balancing equations, and differentiating between procedural success and true grasp of what an equation represents at the particle level are all common challenges for learners. According to studies, students frequently have trouble understanding the chemical significance of stoichiometric ratios exactly a submicroscopic representation problem despite being able to use a balanced-equation technique (Han et al., 2023; Kusumawati et al., 2024).

Misconceptions regarding limiting reactants, mass/atom conservation, and proportional reasoning in symbolic, numerical, and particle forms are common manifestations of these challenges (Ghimire, 2024; Shaafi et al., 2025).

Therefore, this research is both innovative and urgent: Two-Tier Diagnostics for Evaluating Submicroscopic Representations in Stoichiometry. First, it places the two-tier structure as a focused evaluator of submicroscopic representational quality in stoichiometric issue contexts (e.g., mapping how students justify ratios, moles, and reaction quantities using particle reasoning submicroscopic representation) in addition to being a misconception detector. Second, it seeks to produce an experimentally supported profile of submicroscopic representation patterns in secondary stoichiometry, giving educators practical proof to rethink lessons that directly connect triplet levels instead of reiterating symbolic-only practices (Royani et al., 2025; Sukaria, 2025; Verma & Choudhuri, 2025). By doing this, the study

directly addresses the chronic lack of submicroscopic competency in Indonesian classrooms as well as the established dominance of algorithmic focus in stoichiometry learning.

## 2. METHOD

### 2.1. Type and Research Procedure

This study focused solely on students' submicroscopic representational abilities in stoichiometry and used a quasi-experimental design with posttest-only comparison. Thirty-three secondary-level students from a single intact class participated in the study. They were purposively selected and split into two groups according to the equivalent baseline ability distribution ascertained from previous academic records and diagnostic mapping. With the use of alternating audiovisual chemistry learning materials, the experimental group ( $n = 16$ ) was instructed using a Problem-Based Learning (PBL) model that was especially created to illustrate submicroscopic representation particle interactions, mole ratios, and reaction processes. The control group ( $n = 17$ ), on the other hand, received instruction utilizing the same PBL approach but without the aid of audiovisual materials; instead, they were only given verbal explanations, textbooks, and symbolic representations. To be sure that any differences detected were due to the influence of audiovisual-supported PBL on submicroscopic representation and not test familiarity effects, both groups were evaluated using a posttest only at the conclusion of the instructional intervention.

All undergraduate students enrolled in the Biology Education Study Program who were enrolled in the Basic Chemistry course during the relevant academic semester made up the study's population. Because Basic Chemistry is a basic course that heavily relies on stoichiometry and demands a high level of submicroscopic representational ability, this population was chosen.

Purposive sampling was used to select the research sample from this group, yielding one intact class of 33 undergraduate students. The uniformity of academic background and the viability of instruction were taken into consideration when selecting this class. The

sample was then split into two groups with similar initial ability distributions: a control group of 17 students who received Problem-Based Learning without audiovisual support, and an experimental group of 16 students who received Problem-Based Learning integrated with audiovisual media. This selection strategy allowed for a targeted analysis of how the instructional intervention affected students' submicroscopic representations in stoichiometry while ensuring comparability between groups.

## 2.2. Research Instrument

A two-tier multiple-choice diagnostic test designed especially to assess students' submicroscopic representations in stoichiometry made up the research tool. Students' content responses pertaining to stoichiometric concepts were evaluated in the first tier, and the reasoning and particulate-level rationale for those responses were examined in the second tier. The instrument's reliability was established before it was put

into use, and it was validated using expert judgment involving chemistry education specialists. Content validity, which was determined by expert judgment, was used to assess the validity of the research instrument. The validation method includes three chemistry education experts in total. The accuracy of the chemical ideas, the suitability of the submicroscopic representations, the clarity of the first-tier questions and second-tier reasoning possibilities, and the alignment of each two-tier item with the learning objectives of stoichiometry were all evaluated by these experts. In order to guarantee that the instrument accurately reflected the intended structures, changes were made in response to the experts' input.

Internal consistency analysis, which was computed using Cronbach's alpha coefficient based on students' replies to the finalized instrument, was used to assess the reliability of the instrument. This approach was selected because it is commonly used in educational research to assess the consistency of multi-item diagnostic assessments. The two-tier diagnostic exam consistently assessed students' submicroscopic representational capacity, as seen by the reliability coefficient that was obtained, which satisfied acceptable criteria. The test blueprint (kisi-kisi) employed in this investigation is shown in Table 1.

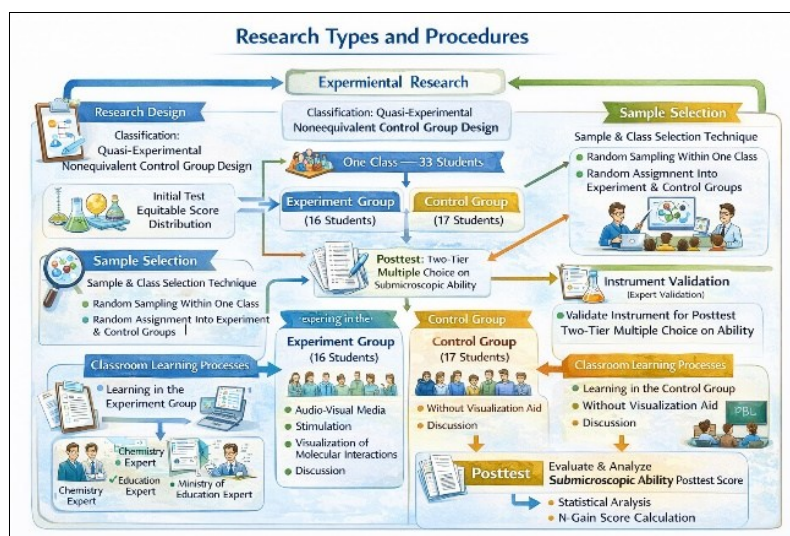


Figure 2. Research procedure

Table 1. Blueprint of two-tier submicroscopic stoichiometry test

Subtopic	Learning Objectives	Two-Tier Multiple-Choice Focus	Item Numbers	Validity & Reliability
Mole concept	Explain mole as particle quantity	Linking moles to number of particles	1–3	Valid ( $V > 0.80$ )
Chemical equations	Interpret equations submicroscopically	Particle ratios in balanced equations	4–6	Valid ( $V > 0.80$ )
Stoichiometric ratios	Relate coefficients to particle proportions	Submicroscopic meaning of coefficients	7–9	Valid ( $V > 0.80$ )
Limiting reactants	Identify limiting reactants conceptually	Particle-level reaction completion	10–12	Valid ( $V > 0.80$ )
Mass–mole relationships	Connect mass to particle quantities	Conservation at submicroscopic level	13–15	Reliable ( $\alpha \geq 0.80$ )

The complete research design and procedural flow used in this investigation are depicted in Figure 2, which offers a thorough overview of the experimental structure from sample selection to data processing. This study used a quasi-experimental nonequivalent control group design, as seen in the picture. The sampling and grouping processes, which combined deliberate selection of the class with random assignment of students into experimental and control groups within the same class environment, are further explained in the figure. This strategy was selected to preserve internal validity and instructional feasibility. While the control group received the same PBL framework without visualization aids, relying primarily on discussion and symbolic representations, the experimental group received PBL integrated with audiovisual media, which included simulations and visualizations of molecular interactions to support submicroscopic reasoning.

Furthermore, the instrument validation procedure is clearly illustrated in Figure 2, which emphasizes that the posttest instrument, a two-tier multiple-choice diagnostic test that assesses submicroscopic representation capacity, was verified by expert opinion before being used. To guarantee uniformity, the same posttest was used to evaluate both

groups. Descriptive statistics, diagnostic category profiling, and effect size calculation were used to study students' replies, as shown in the figure's last stage. This allowed for a methodical assessment of the instructional influence. All things considered, Figure 2 acts as a procedural road map that improves transparency and makes it possible for readers to follow the methodological reasoning behind the research.

## 2.3. Data Collection Techniques

Data was gathered in a methodical manner throughout a number of phases. Initially, both groups were given the two-tier diagnostic tool as a posttest following the conclusion of the instructional intervention. To ensure fairness and reduce outside effects, the test was administered under standardized conditions. Second, a tiered scoring system was used to grade the students' responses; full conceptual knowledge was only awarded when both the first-tier response and the second-tier reasoning were accurate. After that, responses were analyzed to find patterns of flawed thinking and levels of submicroscopic comprehension. To

uphold research ethics and confidentiality, all data were collected and coded anonymously.

## 2.4. Data Analysis

Comparing students' submicroscopic representational skills between the experimental and control groups was the main goal of the data analysis. Students' performance in each stoichiometry subtopic was profiled using descriptive statistics (mean, standard deviation, and percentage of accurate two-tier responses). To ascertain if the audiovisually supported PBL model resulted in a statistically significant difference in posttest results when compared to PBL without media support, inferential analysis was carried out using an independent samples t-test. The assumptions of homogeneity and normalcy were investigated before hypothesis testing. Effect size (Cohen's d) was used to further measure the instructional effect's magnitude and determine the intervention's practical importance. This analytical method made it possible to conduct a targeted assessment of the ways in which the use of instructional media in PBL affects students' capacity to create and use submicroscopic representations in stoichiometry.

## 3. RESULT AND DISCUSSION

### 3.1. Result

Research The study's empirical results are presented in this section, with an emphasis on students' submicroscopic representational skills in stoichiometry as determined by a two-tier diagnostic test. Following a thorough presentation of descriptive statistical results and visual analyses contrasting the experimental and control groups, the results are arranged to describe the distribution of research participants. These results offer a solid basis for analyzing how audiovisual-supported problem-based learning affects submicroscopic comprehension.

The results suggest, theoretically, that the submicroscopic quality of pupils' mental models is the primary cause of their stoichiometry issues. The control group's students mostly depended on algorithmic formula manipulation, indicating the existence of syntactic mental models that function at the symbolic level without any significant connection to particle processes. Students in the PBL group with audiovisual help, on the other hand, more often displayed integrated mental models, wherein

symbolic equations were logically linked to particle ratios, chemical interactions, and conservation principles. This distinction is consistent with the representational competence theory, which holds that coordinated thinking at the symbolic, macroscopic, and submicroscopic levels is necessary for meaningful chemistry learning.

Regarding conceptual coherence, the two-tier diagnostic profiles show that students' internal consistency and accuracy were both impacted by instructional support. The experimental group's higher percentage of Tier 1 Correct–Tier 2 Correct answers suggests that students were able to sustain consistent conceptual connections between their calculations and their particle-level conceptualizations. On the other hand, the control group's continued use of disjointed and misconception-based categories illustrates disordered knowledge frameworks, in which discrete ideas are used inconsistently in various settings. Constructivist learning theory, which emphasizes that information integration rather than procedural fluency alone is essential to conceptual understanding, is supported by this finding.

Pedagogically, these findings show that without specific visualization and representational scaffolding, Problem-Based Learning is not enough to solve representational problems in stoichiometry. It seems that audiovisual materials serve as external cognitive supports that lessen cognitive load and abstraction, allowing students to improve their mental models and externalize unseen processes. The study suggests that in order to effectively teach stoichiometry, inquiry-oriented pedagogies should be purposefully combined with diagnostic tests and representational tools that focus on submicroscopic thinking. Supporting long-lasting conceptual transformation and linking learning paths from secondary to tertiary chemistry education require this kind of integration.

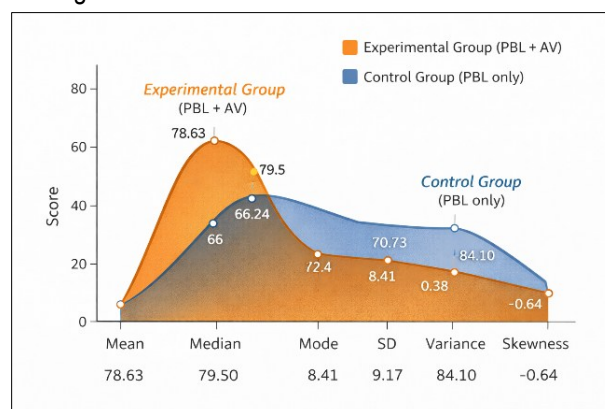


Figure 3. Overall descriptive statistics of submicroscopic representation scores

A distinct structural difference between the two educational situations is evident in figure 3, which displays the overall descriptive statistics of the students' submicroscopic representation scores. The experimental group performs better centrally in understanding stoichiometric ideas at the particle level, as evidenced by a much higher mean and median than the control group. The reduced variance and standard deviation further imply that PBL aided by audiovisual aids not only improved student performance but also fostered more uniform conceptual comprehension (Su et al., 2025). This is important from the perspective of chemical education because stoichiometry necessitates coordinated thinking about proportionality, conservation, and particle ratios; less dispersion suggests fewer disjointed or unstable mental models (Jelodari et al., 2025). While the control group's positive skewness shows the survival of lower-level submicroscopic understanding, the experimental group's slightly negative skewness suggests a clustering toward better performance.

Table 2. Distribution of students by diagnostic category (Two-Tier Analysis)

Group	High Understanding	Partial Understanding	Misconception
Experimental	46.9%	34.4%	18.7%
Control	23.5%	41.2%	35.3%

By employing two-tier diagnostic categories to categorize student replies, Table 2 expands on this view. While the percentage of misconceptions in the control group was nearly double, nearly half of the experimental group attained high-level understanding, compared to less than one-quarter in the control group. This pattern is crucial from a teaching standpoint since two-tier diagnostics show if pupils have cohesive submicroscopic reasoning in addition to whether their answers are right. A well-known source of difficulty in learning stoichiometry, namely the predominance of algorithmic reasoning divorced from chemical meaning, may have been mitigated by audiovisual representations, as evidenced by the experimental group's notable decrease in misconceptions. These representations helped students visualize invisible entities, such as reacting particles and mole ratios (Sterner, 2025).

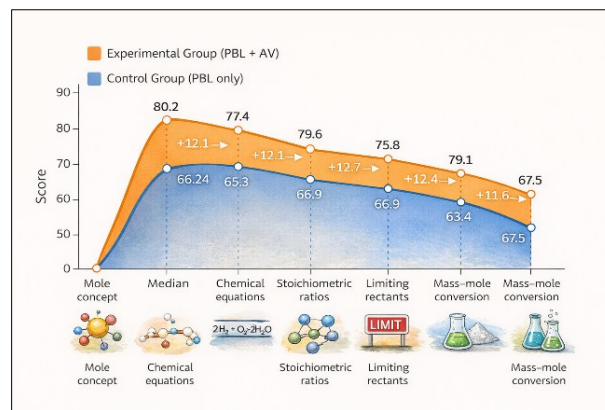


Figure 4. Subtopic-level performance on submicroscopic stoichiometry

Figure 4 shows evidence at the subtopic level that the instructional effect is continuous throughout the stoichiometry conceptual structure. The experimental group's mean differences in all five subtopics mole concept, chemical equations, stoichiometric ratios, limiting reactants, and mass-mole conversion exceed 11 points. Significantly, from basic particle counting to dynamic response limitations, these subtopics reflect increasing conceptual complexity. The continuous benefit implies that rather than focusing on discrete skills, audiovisual-supported PBL enhanced a transferable submicroscopic representational framework. In the context of teaching chemistry, this means that pupils have successfully internalized the idea that matter is particulate, allowing them to understand symbolic representations as mirror images of the interactions between particles.

Table 3. Effect size estimation of instructional treatment

Comparison	Cohen's d	Effect Magnitude
Experimental vs Control	1.41	Large

Through effect size analysis, Table 3 summarizes these results, showing a Cohen's d of 1.41, which represents a significant and educationally significant effect. Such a magnitude is significant for teaching stoichiometry in higher education because the abstract and technically demanding nature of the subject has historically made it resistant to intervention (da Silva Ferry & de Assis, 2024; Paredes-Turra et al., 2025). A large effect size suggests that learning gains were both statistically significant and practically transformational as a result of the instructional design, especially the

incorporation of audiovisual resources within a problem-based learning framework. This enhances the manuscript's contribution from the standpoint of the reviewer by proving instructional impact that goes beyond usual incremental changes.

### 3.2. Discussion

In order to interpret how the incorporation of audiovisual-supported problem-based learning affects students' submicroscopic representations in stoichiometry, this discussion section summarizes the research findings. Using two-tier diagnostic analysis to uncover patterns of comprehension, cognitive demand, and misunderstanding profiles, the conversation is structured with a focus on how students coordinate symbolic, macroscopic, and particle representations. This section attempts to explain not only if learning outcomes improved but also how and why particular instructional supports enabled deeper conceptual understanding in Basic Chemistry learning by placing the results within known frameworks of chemistry education.

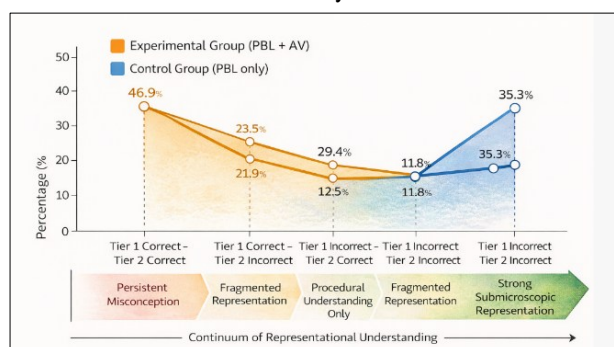


Figure 5. Two-tier diagnostic profile of students' submicroscopic representation ability

Students' submicroscopic representational ability is mapped along a continuum from persistent misconceptions to strong submicroscopic knowledge using the two-tier diagnostic trajectory shown in Figure 5. In order to understand learning outcomes as conceptual movement rather than just static percentages, the experimental group (PBL supported by audiovisual media) and the control group (PBL only) are compared across four diagnostic categories. Increasing representational quality is reflected in the category ordering, which makes it clear how training affects students' cognitive posture throughout stoichiometry learning.

The experimental group shows a significantly higher percentage of students (46.9%) at the highest level

(Tier 1 Correct–Tier 2 Correct) than the control group (23.5%), suggesting that audiovisual-supported PBL allowed almost twice as many students to combine accurate symbolic answers with logical particle-level explanations. On the other hand, there is a significant accumulation in the Tier 1 Incorrect–Tier 2 Incorrect category (35.3%) for the control group, indicating enduring misconceptions. This difference demonstrates how PBL without clear visual scaffolding frequently leaves students dependent on surface-level processes and unable to relate stoichiometric symbols to underlying particle processes.

The teaching procedure is further clarified by the intermediate categories. While the experimental group's decreased presence of fragmented representations implies that audiovisual media stabilized partial conceptual discoveries, higher proportions of procedural comprehension only in the control group indicate algorithmic achievement without submicroscopic meaning. The combined trajectories in Figure 6 highlight the crucial role that representational support plays in meaningful stoichiometry learning by showing how incorporating audiovisual representations into PBL causes students to move from misconception-dominated profiles toward coherent submicroscopic reasoning.

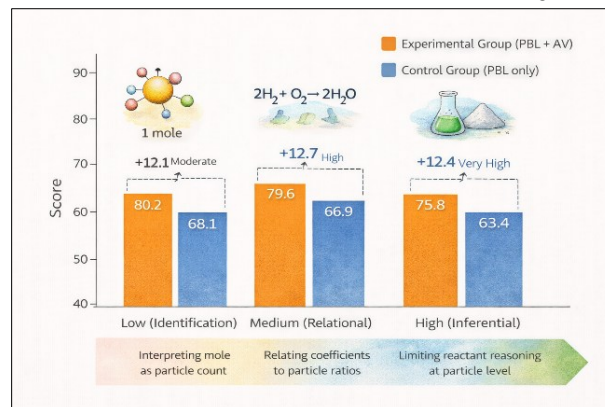


Figure 6. Submicroscopic representation performance by stoichiometry cognitive demand

A comparison of students' submicroscopic representation performance at three different levels of stoichiometry cognitive demand low (identification), medium (relational), and high (inferential) is shown in Figure 6. The comments show the extent of conceptual gaps at each level, and the bar chart compares the experimental group (Problem-Based Learning aided by audiovisual media) with the control group (PBL only).

Because of this structure, the results can be viewed as signs of how instructional design interacts with increasing cognitive complexity in stoichiometric reasoning rather than just as score differences (Garcia, 2025).

The experimental group performs somewhat better than the control group (+12.1) at the low cognitive load level, which entails recognizing the mole as a particle-counting unit. This shows that by giving abstract quantities like the mole a visual form, audiovisual representations successfully reinforced fundamental submicroscopic notions (Minga, 2024; Sadok et al., 2024). The experimental group's advantage suggests that detailed particle-level visualization improves even fundamental stoichiometric knowledge, even though both groups had comparatively higher scores at this level.

The conceptual gap increases (+12.7) when students are required to relate coefficients in chemical equations to particle ratios at the medium cognitive effort level. The shift from recognition to relational reasoning, where students must coordinate symbolic equations with submicroscopic interpretations, is reflected in this growth. While the control group demonstrated difficulties converting coefficients into significant particle associations, the experimental group's superior performance suggests that audiovisual-supported PBL enabled the integration of symbolic and particulate representations (Almulla, 2020; Lavado-Anguera et al., 2024).

The level of high cognitive effort, which involves inferential reasoning on particle-level reactant limitation, exhibits the greatest pedagogical contrast (+12.4, extremely high gap). Here, the control group's lower scores show that they continue to struggle with the well-known stoichiometry learning issue of understanding reaction completion and particle availability. The superior performance of the experimental group, on the other hand, shows that audiovisual materials provide crucial representational scaffolding, allowing students to use higher-order inferential reasoning. All all, this figure offers strong proof that when stoichiometric problems require more complex submicroscopic reasoning, the benefits of audiovisual-supported PBL become more noticeable (Jia et al., 2023; Smith et al., 2022).

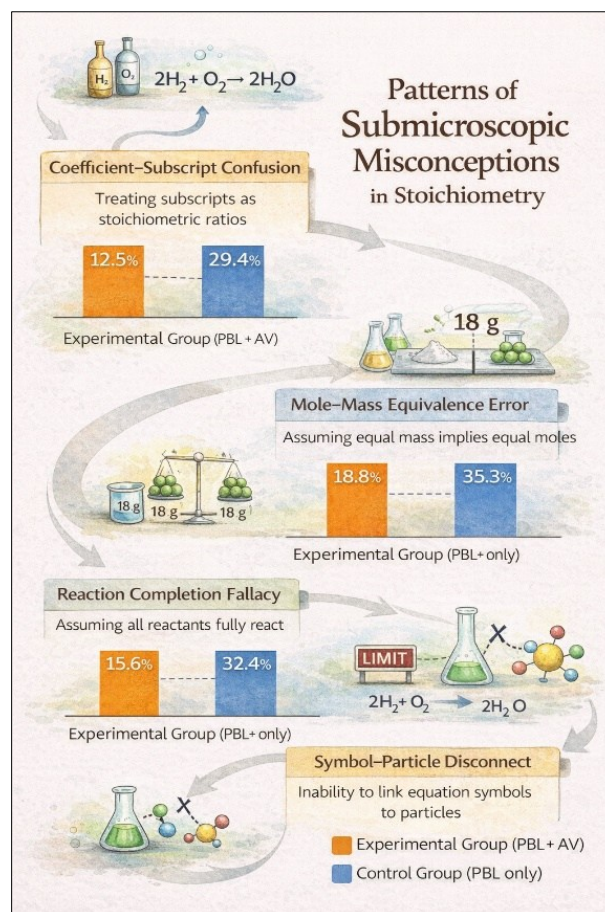


Figure 7. Patterns of submicroscopic misconceptions identified through two-tier analysis

By contrasting the experimental group (Problem-Based Learning assisted by audiovisual media) with the control group (PBL only), Figure 7 illustrates the prevalent patterns of submicroscopic mistakes in stoichiometry. The diagram's purposeful sequential movement shows how misconceptions arise and endure when pupils are unable to combine particulate-level thinking with symbolic chemical representations. The picture highlights that these mistakes are conceptual and representational in character rather than just computational by placing each assumption inside a specific stoichiometric framework.

Compared to the control group (29.4%), the experimental group (12.5%) exhibits a much lower frequency of the first misconception, coefficient-subscript confusion. This suggests that the distinction between coefficients as particle ratios and subscripts as molecular composition was successfully made clear by audiovisual representations. Students in the control group tended to misunderstand chemical formulas in the absence of such

visual scaffolding, which perpetuates a widespread symbolic mistake that compromises sound stoichiometric reasoning.

When it comes to the mole mass equivalency error and the reaction completion fallacy, the control group regularly exhibits almost twice as many misconceptions as the experimental group. These results imply that students who did not have access to audiovisual aids had difficulty understanding the mole as a count of entities and identifying limiting reactants at the particle level. On the other hand, the experimental group's lower occurrence of misconceptions suggests that dynamic visualizations helped students coordinate the relationships between mass, mole, and particle in responding systems.

The symbol–particle gap is the most common misunderstanding in both groups; 41.2% of students in the control group and 21.9% of students in the experimental group were unable to relate equation symbols to particulate activities. This finding highlights a basic difficulty in learning stoichiometry: the inability to convert symbolic equations into useful submicroscopic models. Overall, the figure offers convincing proof that by bolstering the submicroscopic representational bridge which is essential to effective chemistry learning the incorporation of audiovisual materials into PBL considerably reduces the generation of misconceptions. The results of this study show that incorporating audiovisual-supported Problem-Based Learning transforms learning from algorithmic competency to conceptually meaningful comprehension by greatly improving students' submicroscopic representations in stoichiometry. Students exposed to explicit visualizations consistently demonstrated stronger particle-level reasoning, fewer persistent misconceptions, and improved consistency between symbolic and submicroscopic representations across diagnostic categories, cognitive demand levels, and misconception patterns. These findings demonstrate that stoichiometry problems are really representational rather than just mathematical, and that specific instructional scaffolding

can successfully address this fundamental problem in chemistry education (Aksela, 2005).

These results suggest that learning strategies that emphasize the submicroscopic level should be consistently incorporated into stoichiometry training, especially in Basic Chemistry courses. To clearly connect chemical symbols, amounts, and particle processes, lecturers and educators should incorporate dynamic visualizations, simulations, and multimedia materials into problem-based assignments (Ismail et al., 2025; Ralević et al., 2025). Additionally, diagnostic testing, like two-tier exams, should be regularly utilized to determine students' underlying reasoning tendencies and provide timely instructional interventions in addition to measuring accomplishment.

A number of complimentary options should be taken into consideration in order to help pupils' conceptual development even more. These consist of guided peer discussions centered on particle models, the use of multiple-representation learning sequences, and formative feedback that clearly distinguishes between sound and flawed submicroscopic reasoning. Adaptive remediation using concept mapping, scaffolded inquiry projects, or simulations may be required for children who still show fragmented comprehension. When combined, these strategies can empower diverse learners, enhance representational ability, and foster a more profound and long-lasting grasp of stoichiometry.

To make sure inferential analysis was adequate, prerequisite statistical assumptions were validated before looking at the instructional effect. The Shapiro-Wilk test was used to analyze the normality of the data, and Levene's test was used to evaluate the homogeneity of variance. The findings supported the use of an independent-samples t-test to compare group means by confirming that the posttest scores from both groups were normally distributed and showed homogeneous variances ( $p > .05$ ). Cohen's  $d$  was then used to assess the instructional effect's magnitude in order to add practical meaning to statistical significance.

Table 4. Summary of assumption tests and inferential statistics

Analysis Stage	Statistical Test	Experimental Group	Control Group	Test Statistic	df	p-value	Interpretation
Normality	Shapiro–Wilk	$W = 0.96$	$W = 0.95$	—	—	$> .05$	Data normally distributed

Homogeneity of variance	Levene's test	—	—	$F = 0.42$	1, 31	.52	Variances homogeneous
Mean comparison	Independent t-test	$M = 78.63$ , $SD = 8.41$	$M = 66.24$ , $SD = 9.17$	$t = 4.03$	31	< .001	Significant difference
Effect magnitude	Cohen's $d$	—	—	$d = 1.41$	—	—	Large effect

As shown in Table 4, the assumption tests verify that the data satisfied the conditions for parametric analysis. In particular, the use of an independent-samples t-test for group comparison was justified because the normality and homogeneity of variance tests revealed no major breaches. Students who participated in Problem-Based Learning with audiovisual support scored significantly higher on submicroscopic representations than those who did not, according to the inferential analysis, which showed a statistically significant difference between the experimental and control groups ( $t(31) = 4.03, p < .001$ ).

Crucially, this statistical significance is complemented by a very large effect size (Cohen's  $d = 1.41$ ), suggesting that the observed difference represents a significant instructional impact rather than being insignificant or purely sample-dependent. Such a magnitude indicates that, rather than generating slight improvements in procedural performance, the intervention significantly changed pupils' conceptual processing at the submicroscopic level, according to educational research.

Table 4 offers solid and convergent empirical evidence that audiovisual-supported PBL significantly improves students' submicroscopic representational ability in stoichiometry by combining assumption testing, inferential statistics, and effect size estimation within a single analytical framework.

#### 4. CONCLUSION

According to the study's findings, students' submicroscopic representational skills in stoichiometry within a Basic Chemistry course are greatly improved by audiovisual-supported Problem-Based Learning (PBL). When compared to students who were taught via PBL alone, students who were exposed to audiovisual media had significantly greater levels of coherent particle-level reasoning and a significant decrease in persisting misunderstandings, according to evidence from two-tier diagnostic analysis. These results support the idea that improved submicroscopic conceptualization, rather than

just procedural mastery, is what drives advances in stoichiometry learning. Additionally, the findings show that the instructional impact improves with cognitive strain, especially for relational and inferential stoichiometric tasks like limiting-reactant reasoning and particle ratio interpretation. This suggests that audiovisual materials serve as crucial scaffolding for representation, allowing pupils to connect symbolic equations to the underlying particle processes. Additionally, the study confirms the usefulness of two-tier diagnostic tools as reliable instruments for assessing students' conceptual knowledge beyond simple accuracy. To sum up, this study offers solid empirical evidence in favor of including diagnostic tests and representationally rich instructional materials into stoichiometry instruction. By highlighting the crucial significance of submicroscopic representations in chemistry education research, the findings provide theoretical contributions and practical implications for chemistry educators looking to foster meaningful learning.

To ensure a fair interpretation of the results, a number of constraints should be noted. First, the results may not be as applicable to larger student groups or diverse institutional contexts due to the study's very small sample size, which was taken from a single entire class. Second, the study used a posttest-only design, which does not directly quantify individual learning improvements over time, even while it accounts for testing effects. Third, the assessment was limited to submicroscopic representational ability as determined by a two-tier diagnostic examination; it did not look at other pertinent learning outcomes including affective aspects, long-term retention, or information transfer. Lastly, even though the educational intervention included audiovisual materials, the study did not compare various visualization styles or levels in a systematic manner, which could have affected the degree of representational support. These drawbacks imply that in order to further support and expand on the current findings, future studies should use longitudinal designs, multi-dimensional assessment techniques, and larger and more varied populations.

## 5. ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the undergraduate students of the Biology Education Study Program, Class D, who were enrolled in the Basic Chemistry course, for their active participation and valuable contributions to this research. Their engagement, cooperation, and commitment throughout the learning and data collection processes made this study possible and meaningful.

## 6. REFERENCES

- Aksela, M. (2005). Supporting Meaningful Chemistry Learning and Higher-order Thinking through Computer-Assisted Inquiry: A Design Research Approach. In *University of Helsinki*.
- Almulla, M. A. (2020). The Effectiveness of the Project-Based Learning (PBL) Approach as a Way to Engage Students in Learning. *SAGE Open*, 10(3). <https://doi.org/10.1177/2158244020938702>
- Alqadri, Z., & Munawwarah. (2025). Mental Models and Conceptual Change in Chemistry: A Literature-Based Perspective on Learning Challenges. *Journal of Educational Sciences*, 9(2).
- Atabek-Yigit, E., Senoz, A. B., & Balkan-Kiyici, F. (2025). Examining teacher candidates' identification of misconceptions. *Teacher Development*. <https://doi.org/10.1080/13664530.2025.2547057>
- da Silva Ferry, A., & de Assis, L. P. (2024). Structural Analysis of an Analogy for Teaching Chemical Stoichiometry: possibilities and limitations. *Revista Eureka*, 21(1). [https://doi.org/10.25267/Rev\\_Eureka\\_ensen\\_divulg\\_cienc.2024.v21.i1.1202](https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2024.v21.i1.1202)
- Damayanti, Y. D., & Putri, R. A. (2025). Cognitive Load Reduction Strategy In Learning Stoichiometry For 3t Students: An Approach To Overcoming Cognitive Load In Chemistry Numeration. *International Journal of Active Learning*, 10(1). <https://doi.org/10.15294/ijal.v10i1.22475>
- de Miranda, L. S., & da Silva Freire, M. (2025). Augmented Reality for Approaching Chemical Reactions: A Pedagogical Experience in High School. *Revista Virtual de Quimica*, 17(1). <https://doi.org/10.21577/1984-6835.20240064>
- Garcia, L. L. W. (2025). A Narrative Inquiry into Chemistry Teachers' Experiences with Stoichiometry. *International Journal of Advanced Multidisciplinary Studies*, V(7).
- Ghimire, P. M. (2024). Bachelor Level Students Misconception in Chemistry Education. *Ganeshman Darpan*, 9(1). <https://doi.org/10.3126/gd.v9i1.68539>
- Han, P., Fan, J., Kong, L., & Zhang, B. (2023). Surface analysis for corrosion measurement. In *Electrochemical and Analytical Techniques for Sustainable Corrosion Monitoring: Advances, Challenges and Opportunities*. <https://doi.org/10.1016/B978-0-443-15783-7.00010-4>
- Ismail, A., Isrokatun, I., Sari, L., Bhakti, D. D., & Kemalia, L. D. (2025). Augmented Reality-Problem Solving Lab: Does It Foster Elementary Students' Understanding of Submicroscopic Phenomena in Physics? *International Journal of Information and Education Technology*, 15(5). <https://doi.org/10.18178/ijiet.2025.15.5.2298>
- Jelodari, Z., Zenouzagh, Z. M., & Hashamdar, M. (2025). Exploring PBL and e-PBL: implications for 21st-century skills in EFL education. *Discover Education*, 4(1). <https://doi.org/10.1007/s44217-025-00773-3>
- Jia, L., Jalaludin, N. A., & Rasul, M. S. (2023). Design Thinking and Project-Based Learning (DT-PBL): A Review of the Literature. *International Journal of Learning, Teaching and Educational Research*, 22(8). <https://doi.org/10.26803/ijlter.22.8.20>
- Kemendikbud Ristek. (2023). PISA 2022 dan Pemulihan Pembelajaran di Indonesia. *Laporan Pisa Kemendikbud Ristek*.
- Kusumawati, A. D., Ariani, S. R. D., & Indriyanti, N. Y. (2024). Effectiveness of the pH Master Application on Acid-Base Concepts as a Digital Alternative to Conventional Laboratory Practices for Enhancing Student Learning Outcomes". *JKPK (Jurnal Kimia Dan Pendidikan Kimia)*, 9(2). <https://doi.org/10.20961/jkpk.v9i2.89855>

- Laukaityte, I., Rolfsman, E., & Wiberg, M. (2024). TIMSS vs. PISA: what can they tell us about student success?—a comparison of Swedish and Norwegian TIMSS and PISA 2015 results with a focus on school factors. *Frontiers in Education*, 9. <https://doi.org/10.3389/educ.2024.1323687>
- Lavado-Anguera, S., Velasco-Quintana, P. J., & Terrón-López, M. J. (2024). Project-Based Learning (PBL) as an Experiential Pedagogical Methodology in Engineering Education: A Review of the Literature. In *Education Sciences* (Vol. 14, Issue 6). <https://doi.org/10.3390/educsci14060617>
- Minga, M. (2024). The National Folklore Festival of Gjirrokastër: An Analysis of its Audiovisual Representation. *Contemporary Southeastern Europe*, 11(2). <https://doi.org/10.25364/02.11:2024.2.6>
- Moju, M., Taylor, L., & Iweuno, B. (2025). Tackling the challenge of chemical representations through sensemaking practices in chemistry education. *Discover Education*, 4(1). <https://doi.org/10.1007/s44217-025-00703-3>
- Moreira da Silva, A., & Barroca, M. J. (2025). Addressing Chemophobia: Bridging Misconceptions in Food Chemistry. In *Applied Sciences (Switzerland)* (Vol. 15, Issue 11). <https://doi.org/10.3390/app15116104>
- Mundy, C. E., Potgieter, M., & Seery, M. K. (2023). A design-based research approach to improving pedagogy in the teaching laboratory. *Chemistry Education Research and Practice*, 25(1). <https://doi.org/10.1039/d3rp00134b>
- Paredes-Turra, C., Huincahue, J., & Ariza, Y. (2025). Teaching stoichiometry through the use of teaching models: A literature review. *Journal of Physics: Conference Series*, 3117(1). <https://doi.org/10.1088/1742-6596/3117/1/012020>
- Pugh, D., & Hogarth, G. (2025). Addressing misconceptions in dithiocarbamate chemistry. In *Dalton Transactions* (Vol. 54, Issue 30). <https://doi.org/10.1039/d5dt01085c>
- Ralević, L., Tomašević, B., Putica, K., Maštrapović, V. M., & Trivić, D. (2025). The Effects of Cooperative Learning in Synchronous Online and Classroom Environments on Thirteen-Year-old Students' Understanding of Dissolution at the Submicroscopic Level. *Journal of Science Education and Technology*. <https://doi.org/10.1007/s10956-025-10277-2>
- Ribič, L., & Devetak, I. (2025). Augmented reality in developing students' understanding of chemistry triplet: a systematic literature review. In *Chemistry Teacher International* (Vol. 7, Issue 1). <https://doi.org/10.1515/cti-2024-0060>
- Royani, S. N. M., Artanti, K. P. I. A., Putri, R. A., & Parno, P. (2025). Analysis of Item Difficulty and Student Misconceptions on Temperature and Heat Using a Two-Tier Diagnostic Test. *Jurnal Ilmiah Pendidikan Fisika*, 9(1). <https://doi.org/10.20527/jjpf.v9i1.14401>
- Sadok, S., Leglaive, S., Girin, L., Alameda-Pineda, X., & Séguier, R. (2024). A multimodal dynamical variational autoencoder for audiovisual speech representation learning. *Neural Networks*, 172. <https://doi.org/10.1016/j.neunet.2024.106120>
- Shaafi, N. F., Yusof, M. M. M., Ellianawati, E., Subali, B., & Raji'e, M. H. H. (2025). Investigating misconceptions about acids and bases among pre-service science teachers. *Journal of Education and Learning*, 19(1). <https://doi.org/10.11591/edulearn.v19i1.21803>
- Silva, F. C., & Sasseron, L. H. (2025). The Positioning of Visual Representations As Epistemic Objects for the Teaching of Organic Chemistry. *Journal of Chemical Education*, 102(2). <https://doi.org/10.1021/acs.jchemed.4c01018>
- Simanjuntak, B. R. N., Wiji, W., & Widhiyanti, T. (2025). Systematic Literature Review: Three-Tier Diagnostic Test to Identifying Misconceptions in Chemistry. *Jurnal Penelitian Pendidikan IPA*, 11(7). <https://doi.org/10.29303/jppipa.v11i7.11011>
- Smith, K., Maynard, N., Berry, A., Stephenson, T., Spiteri, T., Corrigan, D., Mansfield, J., Ellerton, P., & Smith, T. (2022). Principles of Problem-Based Learning (PBL) in STEM Education: Using Expert Wisdom and Research to Frame Educational Practice. *Education Sciences*, 12(10). <https://doi.org/10.3390/educsci12100728>

- Sterner, H. (2025). Using Graphical Representations to Develop Students' Correspondence Relationships and Covariational Thinking in Pattern Generalizations in Primary School. *International Journal of Science and Mathematics Education*, 23(6). <https://doi.org/10.1007/s10763-024-10520-z>
- Su, T., Liu, J., Meng, L., Luo, Y., Ke, Q., & Xie, L. (2025). The effectiveness of problem-based learning (PBL) in enhancing critical thinking skills in medical education: a systematic review and meta-analysis. *Frontiers in Education*, 10. <https://doi.org/10.3389/educ.2025.1565556>
- Sukaria, M. I. (2025). Transformasi tes diagnostik two tier ke four-tier berbasis representasi jamak pada konsep atom dan molekul. *Arfak Chem: Chemistry Education Journal*, 8(1). <https://doi.org/10.30862/accej.v8i1.921>
- Torres, D., Xu, A., & Abrams, B. (2025). Disentangling the Dissolution of Ionic and Molecular Compounds: Alternative Conceptions and Teaching Considerations in Chemistry. *Journal of Chemical Education*, 102(7). <https://doi.org/10.1021/acs.jchemed.5c00307>
- Verma, P., & Choudhuri, R. (2025). at Faculty of Education (K) BHU. \*\* Professor, Faculty of Education (K) BHU. Identification of Students' Misconceptions in Biology through Two-tier Diagnostic Test. In *National Journal of Education* (Vol. 1).
- Wannomai, M., Nuangchalerm, P., & Ahmad Zaky El Islami, R. (2024). Stoichiometry understanding of upper secondary students through active science learning. *Journal of Education and Learning*, 18(4). <https://doi.org/10.11591/edulearn.v18i4.20962>