26 (4), 2025, 2420-2435

Jurnal Pendidikan MIPA

e-ISSN: 2685-5488 | p-ISSN: 1411-2531

https://jpmipa.fkip.unila.ac.id/index.php/jpmipa

Mapping the Evolution of Students' Submicroscopic Representations: A Correspondence Analysis of Solute–Solvent Interactions

Suandi Sidauruk* & Ruli Meiliawati

Department of Chemistry Education, University of Palangka Raya, Indonesia

Abstract: Understanding the particulate nature of matter in solutions requires integrating macroscopic, submicroscopic, and symbolic representations, a domain in which students often encounter misconceptions. This study investigated high school students' conceptions of solute-solvent particle behavior in sugar and sodium chloride (NaCl) solutions using student-generated drawings. A total of 253 students from Grades 10, 11, and 12 in Palangka Raya, Indonesia, participated in a descriptive-comparative cross-sectional study. The open-ended pictorial test was validated by experts (Aiken's $V = 0.91$), demonstrated substantial inter-rater reliability (Cohen's $\kappa = 0.753$ for SSR; $\kappa = 0.779$ for CIR; $p < .001$), providing strong evidence of construct validity. Students' representations were categorized into two dimensions: (1) Spatial Structural Representations (SSR): Regular-Loose (Rel), Regular-Dense (Red), Random (Ran), and Invisible/Disappeared (Dis); and (2) Chemical Interaction Representations (CIR): Molecular (MOR), Partial Ionic (PIR), Scientific Ionic (SIR), and Complex Mixed Ionic (MIR). Chi-square analysis revealed a significant relationship between grade level and both representational dimensions (SSR: $\chi^2(6) = 29.079$, $p < .001$, Cramer's $V = 0.24$, inertia = 0.115; CIR: $\chi^2(6) = 61.612$, $p < .001$, Cramer's $V = 0.349$, inertia = 0.244). Correspondence analysis further revealed a progressive conceptual shift: Grade 10 students predominantly depicted Regular-Loose (solid-like) structures, whereas Grade 12 students more frequently produced Random (scientific) representations. Similarly, development in CIR moved from molecular (MOR/PIR) to scientifically accurate ionic forms (SIR/MIR). These findings highlight the need for multi-representational, visually oriented instruction, such as animations, augmented-reality simulations, and drawing-based assessments, to support conceptual change and strengthen coherence across representation levels.

Keywords: particulate nature of matter, solution chemistry, correspondence analysis, representational competence, conceptual change.

▪ INTRODUCTION

Research on students' representations of natural phenomena continues to draw significant attention in science education, particularly in chemistry. This interest arises because many chemistry concepts are inherently abstract, making them susceptible to interpretations that differ from scientific views. Such deviations are commonly known as alternative conceptions or misconceptions. Driver et al. (1985) emphasized that students do not enter the classroom as blank slates; instead, they possess prior conceptions that shape their understanding.

Students' comprehension of solutions is fundamental in chemistry learning, as it forms the basis for more advanced topics such as equilibrium, kinetics, and environmental chemistry (Gilbert & Treagust, 2009; Chandrasegaran et al., 2011). Align with global educational demands, 21st-century scientific literacy requires students not only to master factual knowledge but also to model microscopic phenomena that explain macroscopic properties of matter (OECD, 2019). Therefore, research into students' mental

Suandi Sidauruk & Ruli Meiliawati
*Email: sidauruksuandi@chem.upr.ac.id

DOI: http://dx.doi.org/10.23960/jpmipa.v26i4.pp2420-2435
Received: 02 September 2025
Accepted: 20 November 2025
Published: 01 December 2025

representations of solutions is essential for supporting meaningful chemistry learning in secondary education.

From a constructivist perspective, knowledge is constructed actively by learners through interactions with objects, experiences, and their environment. Such interactions may lead to misunderstandings. Constructivist theory posits that when initial conceptions are inconsistent with scientific explanations, they may evolve into persistent misconceptions (Driver et al., 1994; Duit & Treagust, 2012). If students' prior conceptions are inaccurate, the knowledge they subsequently build will also be flawed. Thus, teachers must first identify students' preconceptions before introducing new concepts. Suparno (1997) argued that knowledge cannot simply be transferred from teachers to students; instead, students must interpret and reconstruct meaning through their own experiences.

Numerous studies in chemistry education have documented misconceptions. Novick and Nussbaum (1981) found that many students believed particles disappear during evaporation. Lee et al. (1993) observed that many sixth-grade students struggle to understand that molecules remain in motion even in solids. Similarly, Sidauruk (2002) reported that university students often depicted gas as concentrated in a single part of a container, suggesting a liquid-like interpretation of gas behavior. Taber (2002) further noted that students frequently imagine ions in solution as static or assume that solutes "disappear." These misconceptions highlight students' difficulties in linking observable phenomena with microscopic interactions.

The concept of solutions is particularly challenging because it involves invisible entities such as ions and molecules. Students' cognitive representations or mental images play a crucial role in shaping their understanding. Research indicates that students experience persistent difficulties in visualizing particle interactions, particularly regarding polarity, dissociation, and homogeneous distribution (Kelly et al., 2010; Naah & Sanger, 2012; Stojanovska et al., 2017). To address this, diagnostic assessments such as two-tier tests, interviews, and drawing tasks have been developed to investigate students' cognitive representations (Chandrasegaran et al., 2007; Adadan & Savaşcı, 2012).

Students often depict solute-solvent interactions inconsistently; particles may appear too dense, too sparse, randomly arranged, or even missing altogether (Naah & Sanger, 2012; Özmen, 2013). Such findings underscore the need for systematic exploration of students' mental images, particularly in the context of high school chemistry. Drawing-based instruments provide rich visual data that can reveal the diversity of students' conceptions (Aykutlu & Bezen, 2010; Adadan, 2014).

Although numerous studies on misconceptions in solution chemistry exist, most focus on macroscopic concepts or quantitative calculations. Detailed explorations of submicroscopic representations remain limited, despite their crucial role in bridging macroscopic observations and symbolic notation. Recent studies demonstrate that interventions grounded in the particulate nature of matter (PNM) can substantially improve students' conceptual understanding (Çalik et al., 2023).

Radzuan & Hanri's (2024) study found that many students still have misconceptions about particle diagram representations, including difficulty understanding particle interactions in solutions, while Hamerská et al. (2024) found that students often rely more on symbolic representations and fail to relate them to the submicroscopic level.

"Therefore, an image-based or visual representation approach is essential. This approach serves as a highly relevant method for exploring students' mental models, as drawings can reflect the conceptual structures they use to interpret chemical phenomena (Chittleborough & Treagust, 2007). Recent studies also emphasize that representational practices in understanding concepts can help students build more meaningful connections across the levels of chemical representation (Moju et al., 2025)."

Research in Palangka Raya and Central Kalimantan has begun to examine students' conceptions of particle behavior in solutions, yet findings remain limited in breadth and depth. Thus, the present study aims to provide an empirical overview of how high school students visually represent solute–solvent interactions. Differences in representation across grade levels were also examined to map conceptual development.

▪ METHOD

Participants

This study involved high school students from Palangka Raya City, Indonesia, which has ten public senior high schools. Sampling was conducted using a multistage random technique: (1) selecting schools, (2) selecting classes, and (3) screening data eligibility. Three schools were randomly chosen from ten accessible and cooperative institutions. From each school, two Grade 10 classes, one Grade 11 science class, and one Grade 12 science class were selected, for a total of 12 classes. All students in these classes (N = 383) participated. Data collection took place in August 2025 using a pictorial particle behavior test. Due to activities related to Indonesia's Independence Day, only 292 answer sheets were returned. After excluding blank or unclassifiable responses, 253 valid responses remained for analysis. Cochran (1954) recommends that each cell in a chi-square contingency table have a minimum frequency of 5, requiring at least 60 participants for the 12 cells in this study. Thus, the sample size exceeded this requirement. Additionally, Hair et al. (2019) suggest that a minimum of 200 participants is adequate for descriptive and relational analysis. Therefore, the sample size of 253 is considered sufficient and representative for the analyses conducted.

Research Design

This study used a descriptive-comparative design with a cross-sectional approach. This design was chosen to describe and compare students' conceptions of the behavior of solvent particles and solutes in solutions at different levels (grades 10, 11, and 12) at the same time of data collection. The descriptive aspect examined the forms of students' mental representations, while the comparative aspect analyzed differences across grade levels. The choice of a cross-sectional design was based on considerations of time efficiency, ease of data collection in a school context, and its relevance for obtaining a "conceptual portrait" of students at various levels of chemistry learning. However, this design cannot attribute differences to developmental progression directly, as cohort effects may influence students' representations. Students completed an open-ended drawing task during a single data collection period.

The research was conducted during a single data collection period (August 2025). Students were given an open written test in their respective classes to draw the behavior of substances in sugar and salt solutions. All drawings were collected and then classified by two independent raters to determine each student's conception category. The research steps included: (1) preparation of drawing instruments and written instructions, (2) administration of the test to a sample of students, (3) collection of illustrated answers, and (4) classification of the results by two raters.

Instrument

The research instrument was an open-ended test that asked high school students to draw illustrations of sugar and salt (NaCl) solutions along with the arrangement of solute and solvent particles. This instrument is a modification of the instrument made by Benson (1993) for drawing gases. Coll & Treagust (2003) stated that drawing assignments are appropriate to explain students' abilities at a microscopic level. The open-ended drawing task was designed exclusively to assess students' submicroscopic representations of solute–solvent interactions. The instrument intentionally did not assess macroscopic observations (e.g., visible dissolution phenomena) or symbolic representations (e.g., chemical formulas or ionic equations). This focus ensured that the data obtained reflected students' mental models at the particulate level, aligning with the study's objective to investigate how students visualize the arrangement and interaction of particles in solution. All instructions, prompts, and scoring criteria were therefore constructed to target the submicroscopic domain, ensuring conceptual fidelity and preventing unintended measurement of unrelated representational levels.

Content validation in this study aimed to ensure that the drawing task measured students' scientific conceptions of solute–solvent particle behavior rather than artistic ability. Content validation was conducted through expert assessment by three experienced chemistry teachers (each with a minimum Master's degree in chemistry education and 15 years of teaching chemistry) to assess the suitability of the content, language clarity, contextual relevance, drawing instructions, and cognitive aspects. This process ensures that the stimulus and drawing instructions are free from ambiguity. The calculation yielded an average Aiken index of 0.91, indicating high content validity (Retnawati, 2016). The lowest value (0.83) was observed in the cognitive aspect due to experts' notes on minor issues related to wording precision, consistency with curriculum concepts, and the suitability of the required cognitive processes for senior high school students. These comments focus on the formulation and representativeness of the items themselves - consistent with the principles of content validity- rather than predicting students' understanding. Therefore, all items were deemed valid and retained for further analysis.

After validation, the instrument was piloted with 95 students (35 grade 10 science students, 30 grade 11 science students, and 30 grade 12 science students). Three raters carried out representations, and two groups of behavioral representations were obtained: Spatial Representation of Substance Structure in Solution (SSR) and Representation of Chemical Interactions of Substances in Solution (CIR). The SSR group has four representation categories, namely: 1) Solvent and dissolved particles are arranged regularly-loosely, Rel, 2) Solvent and dissolved particles are arranged regularly-dense, Red, 3) Solvent and dissolved particles are randomly distributed, Ran, and 4) Solvent and dissolved particles disappear/are not visible, Dis (Figure 1).

CIR group has four representation categories, namely: 1) Molecular representation, MOR, sugar dissolved in water (Figure 3), 2) Partial ionic representation, PIR, water is depicted as dissociating into H^+ and OH^-, although this is a misconception (Figure 3), 3) Scientific ionic representation, SIR, $NaCl \rightarrow Na^+ + Cl^-$ in a water solvent (Figure 4), and 4) Complex mixed ionic representation, MIR, Na^+, Cl^-, H^+, OH^-, H_2O, which reflects

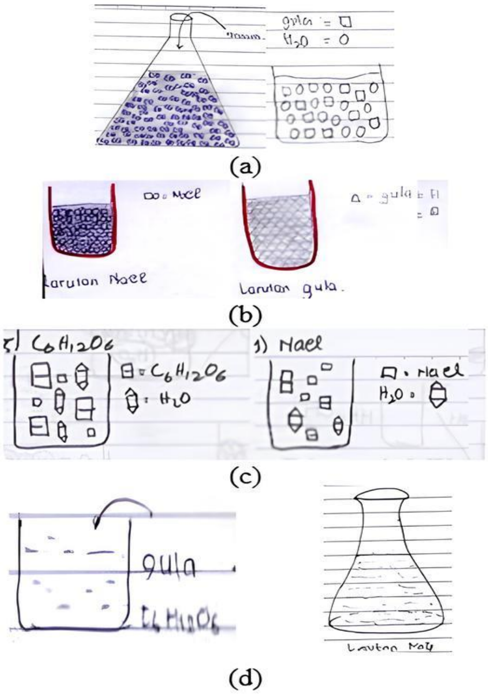

Figure 1. Students' representations of salt and sugar solutions across four identified categories: (a) Regular-Loose (Rel), (b) Regular-Dense (Red), (c) Random (Ran), and (d) Invisible/Disappeared (Dis). Each drawing reflects a distinct conceptual understanding of particle arrangement and solute-solvent interaction. (Source: Primary data, 2025).

students' attempts to understand the solvent as an active participant (Figure 6). Returned blank papers and images irrelevant to these categories were not classified.

An inter-rater reliability test was conducted to assess the level of consistency between two assessors in classifying students' representations of the behavior of solute and solvent particles. The results of the analysis using the Kappa coefficient (K) showed K = 0.753 for the SSR category and K = 0.779 for the CIR category, with $p < 0.001$ in two independent tests of 253 student answer sheets. This value indicates substantial agreement between the two assessors. This indicates that the category/construct structure developed in the Rel, Red, Ran, and Dis rubrics, as well as the MOR, PIR, SIR, and MIR rubrics, is consistently understood by the independent assessors, so it can be concluded that evidence of the instrument's internal structure supports its construct validity (Messick, 2009; Mandrekar, 2011).

Data Analysis

The data resulting from the classification of student answers were analyzed quantitatively and descriptively. The frequency of students in each conception category was calculated and expressed as a percentage. To test whether particle representation patterns differed across grade levels, the researcher used the chi-square (χ^2) test on the distribution of image categories. The χ^2 test was chosen appropriately because the data were categorical frequencies. This analysis method aligns with the research objective of describing the distribution of student conceptions. As a comparison, Berg (2012) also used a simple comparative analysis to test the effect of representation form on solution understanding, although in the context of calculating chemical concentrations. To test the strength of the relationship between representation categories by grade level, a Cramér's V (effect size) was computed. If the χ^2 test was significant, further testing was carried out using the Bonferroni test to determine pairwise comparisons between categories, thereby assessing differences in category distributions between classes. Furthermore, Correspondence analysis was used to determine the pattern of relationships between categories of the class variable and representation categories. Data were analyzed using IBM SPSS Statistics 25.0.

▪ RESULT AND DISSCUSSION

Representation of SSR and Grade Levels

The results of the Chi-square analysis (Table 3) showed a significant difference in behavior toward solvent and dissolved particles across grade levels of high school students ($\chi^2(6) = 29.079$; $p < 0.001$). This finding confirms that students' abilities in representing particle behavior at the microscopic level are not uniform across grade levels. In other words, there are different conceptual development dynamics between students in grades 10, 11, and 12. The Linear-by-Linear Association value (10.650; p = 0.001) also shows a linear trend, indicating that the differences in representation categories follow a consistent direction as grade level increases. This aligns with Chiu's (2007) findings that students' conceptions shift through learning experiences and interactions with chemistry learning materials.

Table 1. Summary of cramer's V for SSR and CIR by grade level

		Value	Asymptotic Standard Error	Approximate T^b	Approximate Significance
Nominal by Nominal					
	Cramer's V (SSR)	.240			.000
	Cramer's V (CIR)	.349			.000

The calculated Cramer's V value was 0.240 (Table 1). Referring to the Cramér's V value table based on degrees of freedom (df; Bobbitt, 2024), the Cramér's V value of 0.24 (df=5) indicates a strong association between educational level and how students represent particle behavior in solution. This suggests that learning experiences, the quality of representational interventions, and exposure to multi-level learning play a role in shaping students' understanding. This supports the findings of Chandrasegaran et al. (2007), who emphasized that students' ability to explain chemical phenomena consistently at the macroscopic, submicroscopic, and symbolic levels is highly dependent on learning strategies that explicitly link these three levels.

Post hoc Bonferroni analysis showed that 10th-grade students displayed more Rel representations than expected, but this difference was not significant. Meanwhile, 12th-grade students displayed more Ran representations, and grade level significantly influenced random representations (Ran). For other representations, grade level did not affect results. This pattern is understandable because, in the early stages, students are often introduced to particle concepts through illustrations of densely packed solids, which leave an impression and influence their representations in solutions (Harrison & Treagust, 2002). Enriching macroscopic, submicroscopic, and symbolic representations in chemistry textbooks is important for supporting the development of accurate representations and preventing misconceptions (Chen et al., 2019; Johnstone, 1991; Gilbert, 2005). These findings emphasize the need for gradual, context-based learning strategies to facilitate students' transition from early to scientific representations.

Table 2. Bonferroni post-hoc comparison results for SSR categories

			Spatial Structural Representations (SSR)				
			Rel	Red	Ran	Dis	Total
Grade	10	Count	58_a	25_a	17_b	22_a	122
		Expected Count	44.4	23.6	33.3	20.7	122.0
	11	Count	23_a	15_a	24_a	13_a	75
		Expected Count	27.3	14.5	20.5	12.7	75.0
	12	Count	11_a	$9_{a, b}$	28_b	$8_{a, b}$	56
		Expected Count	20.4	10.8	15.3	9.5	56.0

A solvent (e.g., water) consists of freely moving water particles (molecules). These particles help separate the solute particles (e.g., sugar) from each other through intermolecular attractions (dipole or hydrogen forces, depending on the solvent type). A sugar solution appears homogeneous because the sugar crystals are completely dissolved. Both sugar and water particles move randomly but remain stable in solution due to attractive forces between them.

The shape of this sugar solution image supports Berg's (2012) findings: 63.4% of students chose the image of sugar particles evenly distributed throughout the solution. The rest of the students chose the image of sugar particles disappearing in the solution, and of sugar particles arranged regularly in the solution, like the arrangement of solid particles.

Correspondence analysis is a multivariate technique specifically designed to explore relationships within and between two or more categorical variables. This analysis examined the relationship between high school students' grade levels (grades 10, 11, and 12) and the categories representing the behavior of solvent and dissolved particles in water: Rel, Red, Ran, and Dis.

Table 3. Summary of chi-square test and inertia for SSR by grade level

					Proportion of Inertia		Confidence Singular Value	
								Correlation
Dimension	Singular Value	Inertia	Chi Square	Sig.	Accounted for	Cumulative	Standard Deviation	2
1	.338	.114			.993	.993	.059	.139
2	.029	.001			.007	1.000	.061	
Total		.115	29.079	.000[a]	1.000	1.000		

The Chi-Square value of 29.079 (p=0.00) indicates a significant relationship between grade level and category of significant SSR representation in a way that statistics can detect. An inertia value of 0.115 indicates a consistent trend of conceptual association between grade level and representation category. This means there is a stable pattern of relationships where 10th-grade students display more Rel representations, while 12th-grade students more often display Ran representations that correspond to scientific concepts. This pattern is not coincidental but reflects students' conceptual development from macroscopic to microscopic understanding.

Dimension 1 accounts for 99.3% of the total inertia, while dimension two accounts for only 0.7%. This pattern indicates a shift in representation from static to dynamic as grade level increases. 10th-grade students more often describe solvent and solute particles as solids that resemble regular solids (Rel category), indicating that they still think at the macroscopic level. Meta-analysis results indicate that students' conceptual difficulties in science, including chemistry, are often caused by a tendency to use analogies and initial models that are inconsistent with scientific concepts. This phenomenon is also evident in students' representations of particle behavior in solutions (Paçacı, 2022).

At the same time, 11th graders occupy an intermediate position, indicating a stage of conceptual restructuring. At this level, students begin to demonstrate a more diverse understanding and attempt to connect macroscopic and submicroscopic ideas, although their representations are not yet entirely consistent. In contrast, 12th graders are strongly associated with the Ran category, which reflects randomly distributed solvent and solute particles. This pattern indicates that most final-grade students have begun to demonstrate a more scientific understanding, namely that particles in solution move freely and randomly due to molecular interactions with water.

However, the analysis also showed that the Red and Dis categories persisted across grade levels. This indicates that some students still harbor conceptual misconceptions, such as the assumption that dissolved substances are “solid and regular” or “disappear” in water. This phenomenon is known as conceptual coexistence, in which two conflicting conceptual models (scientific and non-scientific) can coexist in students' cognition and be used interchangeably depending on the question's context. This phenomenon is also found in chemistry learning, where individuals maintain initial conceptions while adopting new scientific ideas without completely replacing them (Wu & Yezierski, 2022). Table 4 presents a description of the correspondence analysis results.

Table 4. Summary of correspondence analysis results: grade level and SSR

Component	Direction of Association	Statistical Meaning	Pedagogical Implications
Dimension 1	Separates Grade 10 (Rel, Red) from Grades 11-12 (Ran), indicating a shift from ordered to scientifically random particle representations.	Accounts for 99.3% of variation (Inertia = 0.115), showing a strong linear pattern of representational development.	Teaching should support the shift from solid-like models to random-motion particle models using visualizations and simulations.
Dimension 2	Captures small internal variation; Dis appears across all grades.	Explains 0.7% of variation, indicating minor heterogeneity in “disappearing” representations.	Targeted remediation (e.g., conceptual interviews) can address students’ misunderstanding of disappearing particles.
Chi-square ($p = 0.000$)	Grade level is significantly associated with representation categories.	Indicates strong statistical association ($\chi^2 = 61.612$; $p < 0.05$).	Learning should be cumulative across grades to support representational growth.

Inertia (0.115)	Shows the overall strength of the association.	Confirms meaningful multivariate structure.	Representational tasks can enhance students' conceptual development.

Representation of CIR and Grade Levels

However, some students drew sugar and water particles separately, with sugar depicted as intact molecules and water represented as dissociated into H^+ and OH^- ions (Figure 2).

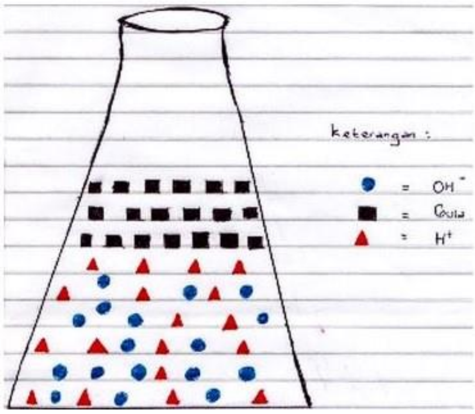

Figure 2. Student drawing of sugar and water particles as separate entities (Source: Primary data, 2025).

Overall, students' representations of sugar solutions fell into two subgroups: sugar–water molecules, MOR category, and sugar molecules with H^+/OH^- ions from water dissociation, PIR category (Figure 3).

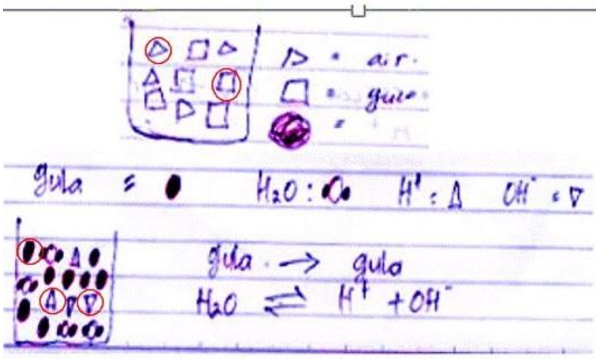

Figure 3. Students' drawing of sugar solution: (a) Sugar-water molecules; (b) Sugar-H+/OH- pairs (Source: Primary data, 2025).

The results indicated that some students still held misconceptions regarding the electrolytic nature of pure water and sugar solutions. Some believe that pure water acts as an electrolyte because it can conduct electricity in daily life contexts. These misconceptions may stem from students' everyday experiences, such as observing that river water can conduct electricity because of dissolved salts and minerals. From this perspective, some students might generalize that pure water is also an electrolyte. However, this interpretation remains speculative, as the present study did not collect specific data (eg, interviews or questionnaires) to verify the origin of this misconception. Scientifically, pure water undergoes only slight autoionization, producing a negligible concentration of H^+ and OH^- ions. In contrast, river water conducts electricity primarily because of dissolved electrolytes, not due to significant ionization of water itself (Ebbing & Gammon, 2009).

When solutes dissolve, intermolecular forces play a critical role. Sugar dissolves without ionization, whereas NaCl dissociates into Na^+ and Cl^- ions. Some students failed to recognize this difference. For example, they depicted NaCl in solution as intact molecules rather than ions (Figure 4), or they paired Na^+ and Cl^- ions together without hydration shells, in the SIR category. Correctly, Na^+ should be surrounded by water's oxygen atoms (δ^-) and Cl^- by hydrogen atoms (δ^+) (Figure 5).

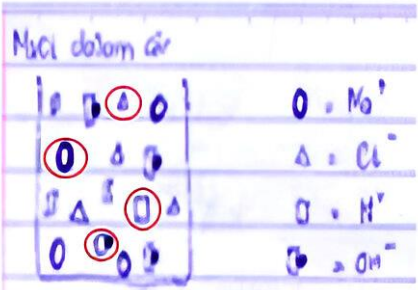

Figure 4. Incorrect student drawings of NaCl solutions as intact molecules (Source: Primary data, 2025).

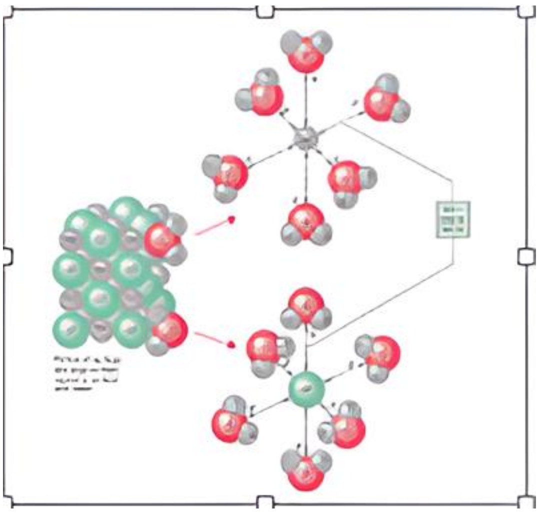

Figure 5. Proper hydration of Na+ and Cl-ions in water (Source: Malone & Dolter, 2010).

NaCl, as the salt of a strong acid (HCl) and a strong base (NaOH), produces a neutral solution that does not significantly increase water's ionization into H^+ and OH^-. Thus, in salt solutions, the correct representation includes only Na^+, Cl^-, and H_2O. Misrepresentations, such as those identified in this study, may mislead students in their understanding of colligative properties. For example, Petrucci et al. (2017) explained that, at equal concentrations, NaCl solutions exhibit greater boiling point elevation than sugar solutions because each NaCl unit dissociates into two particles, whereas sugar molecules do not dissociate.

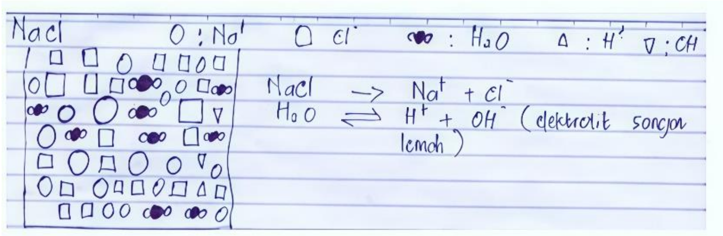

Figure 6. Student drawing showing Na+, Cl-, H2O, H+, and OH- particles together, MIR (Source: Primary data, 2025).

The computed Cramer's V value was 0.349 (df = 5; Table 1), which, based on effect size criteria adjusted for degrees of freedom (Bobbitt, 2024), indicates a strong influence of educational level on students' Chemical Interaction Representations (CIR). Bonferroni-adjusted post-hoc tests showed no significant differences across Grades 10, 11, and 12 for the MOR, PIR, and SIR categories, as indicated by identical subscript letters ($p \geq 0.05$). In contrast, the Mixed Ionic Representation (MIR) category demonstrated a clear developmental pattern: Grade 12 students produced MIR representations at a significantly higher rate than Grade 10 ($p < 0.05$), while Grade 11 occupied an intermediate, non-significant position. These results suggest that representational development is not evident in the basic categories (MOR, PIR, SIR) but becomes apparent in the more complex MIR category.

Table 5. Bonferroni post-hoc comparison results for CIR categories

			Chemical Interaction Representations (CIR)				
			MOR	**PIR**	**SIR**	**MIR**	**Total**
Grade	10	Count	63_a	25_b	22_b	12_c	122
		Expected Count	40.5	24.6	25.1	31.8	122.0
	11	Count	16_a	17_a	20_a	22_a	75
		Expected Count	24.9	15.1	15.4	19.6	75.0
	12	Count	5_a	9_a	10_a	32_b	56
		Expected Count	18.6	11.3	11.5	14.6	56.0
Total		Count	84	51	52	66	253
		Expected Count	84.0	51.0	52.0	66.0	253.0

The results of the correspondence analysis testing the relationship and its strength between levels of class and CIR are presented in Table 6. The Chi-Square value of 61.612 ($p=0.00$) indicates a significant relationship between grade level and the category with the most CIR representation.

This relationship is quite strong, as indicated by the inertia value = 0.244. Dimension 1 accounts for 93.8% of the total inertia, while dimension two only accounts for 6.2%. This indicates that the first dimension explains almost all the variation in the association, so the main interpretation focuses on it. In general, these results show a

Table 6. Summary of chi-square test and inertia for CIR by grade level

Dimension	Singular Value	Inertia	Chi Square	Sig.	Proportion of Inertia: Accounted for	Proportion of Inertia: Cumulative	Confidence Singular Value: Standard Deviation	Confidence Singular Value: Correlation 2
1	.478	.228			.938	.938	.052	.273
2	.123	.015			.062	1.000	.064	
Total		.244	61.612	.000[a]	1.000	1.000		

pattern of conceptual development from molecular representations to more complex scientific ionic representations as the grade level increases.

These findings underscore the persistence of misconceptions in solution chemistry. Posner et al. (1982) suggested that teachers should create cognitive conflict and supportive environments to facilitate conceptual change. According to him, chemistry instruction should integrate macroscopic phenomena with submicroscopic and symbolic representations to avoid fragmented understanding.

Table 7. Summary of correspondence analysis results: grade level vs CIR

Component	Direction of Association	Statistical Meaning	Pedagogical Implications
Dimension 1	Grade 10 (Rel, Red) differs from Grades 11–12 (Ran), showing a shift from ordered to random particle views.	Explains 99.3% of variation (Inertia = 0.115).	Emphasize the transition from solid-like to random particle models using visuals and simulations.
Dimension 2	Minor variation; Dis appears across all grades.	Contributes 0.7% of the variation.	Provide individual remediation for “disappearing particle” misconceptions.
Chi-square ($p = 0.000$)	Grade level is significantly related to the representation category.	Strong association ($\chi^2 = 61.612$; $p < 0.05$).	Use cumulative, grade-sequenced instruction.
Inertia (0.115)	Indicates overall association strength.	Confirms meaningful multivariate pattern.	Use representational tasks to support conceptual development.

Pedagogically, these results indicate that the development of students' conceptions of particle behavior is not linear. Increasing levels do not automatically result in more scientific understanding, but rather through a process of gradual restructuring and conceptual reflection. Therefore, chemistry instruction should emphasize the use of multiple representations -macroscopic, microscopic, and symbolic- to help students connect observable phenomena with appropriate particle models. As Sanchez (2025) emphasizes, integrating these multiple levels of representation not only facilitates students' conceptual understanding of chemical processes but also enhances their perceived usefulness and ease of learning, as each level provides complementary perspectives that support meaning-making in chemistry. Furthermore, the use of particle animations, 3D visual models (including AR), and drawing tasks that model particle behavior can help students confront their misconceptions and strengthen their scientific understanding. Studies show that animations/AR improve submicroscopic visualization, drawing tasks uncover and challenge misconceptions, and 3D models enhance students' visual-spatial abilities (Levy, 2024; Peperkorn et al., 2024; Stammes, 2025).

▪ CONCLUSION

This study revealed that high school students' representations of the particulate nature of matter in solutions can be categorized into four Spatial Structural Representations (SSR) -Regular-Loose (Rel), Regular-Dense (Red), Random (Ran), and Invisible/Disappeared (Dis)-which together reflect a conceptual progression from concrete, solid-like particulate views toward more scientifically accurate models. The dominance of Regular categories among lower-grade students and the increasing proportion of Random representations in higher grades indicate an ongoing reconstruction of students' mental models at the spatial-structural level.

In addition to SSR, this study also demonstrated clear developmental patterns in students' Chemical Interaction Representations (CIR). Students progressed from depicting molecular representations (MOR) and partial ionic representations (PIR) toward more scientifically appropriate ionic representations (SIR) and, ultimately, more complex mixed ionic representations (MIR). The strong association between CIR and grade level (Cramer's V = 0.349) suggests that conceptual understanding of solute-solvent interactions becomes increasingly sophisticated as students advance through their chemistry coursework. The correspondence analysis further indicated that Grade 12 students were more likely to produce MIR representations, reflecting emerging awareness of hydration interactions, ion-dipole forces, and the active role of water molecules in dissolution processes.

These findings emphasize that conceptual development in both SSR and CIR is neither uniform nor linear. Instead, students' representational growth involves gradual restructuring that depends heavily on learning experiences, opportunities to engage with multiple levels of representation, and explicit instructional scaffolding. Therefore, chemistry instruction should integrate macroscopic demonstrations, submicroscopic visualizations, symbolic explanations, and drawing-based assessments to help students build coherent mental models. Image-based discussions, dynamic simulations, augmented-reality visualizations, and guided representational tasks are recommended to confront misconceptions and promote conceptual change.

The main limitation of this research lies in its descriptive-exploratory nature, which does not examine causal relationships between instructional variables and representational development. Future studies should employ experimental, longitudinal, or mixed-method designs to examine mechanisms underlying students' progression from basic molecular depictions to scientifically accurate ionic interaction models. Additionally, integrating digital visualization tools and virtual laboratory environments may provide deeper insights into how spatial–visual experiences contribute to the accuracy of students' SSR and CIR, ultimately supporting the development of evidence-based instructional frameworks to transform students' conceptual understanding of particulate behavior in solutions.

▪ REFERENCES

Adadan, E., & Savaşcı, F. (2012). An analysis of 16–17-year-old students' understanding of solution chemistry concepts using a two-tier diagnostic instrument. *International Journal of Science Education, 34*(4), 513–544. https://doi.org/10.1080/09500693.2011.636084

Adadan, E. (2014). Investigating the influence of model-based instruction on preservice chemistry teachers' understanding of the particulate nature of matter. *Chemistry Education Research and Practice, 15*(2), 219–229. https://doi.org/10.1039/C3RP00106K

Aykutlu, I., & Bezen, S. (2010). Misconceptions of high school students related to chemical bonding. *Procedia – Social and Behavioral Sciences, 2*(2), 766–770. https://doi.org/10.1016/j.sbspro.2010.03.100

Benson, D. L., Wittrock, M. C., & Baur, M. E. (1993). Students' preconceptions of the nature of gases. *Journal of Research in Science Teaching, 30*(6), 587–597. https://doi.org/10.1002/tea.3660300605

Berg, K. de. (2012). A study of first-year chemistry students' understanding of solution concentration at the tertiary level. *Chemistry Education Research and Practice, 13*(1), 8–16. https://doi.org/10.1039/C1RP90057J

Bobbitt, Z. (2024, February 12). How to interpret Cramer's V (with examples). *Statology*.

Çalik, M., Ültay, N., Bağ, H., & Ayas, A. (2023). Effectiveness of particulate nature of matter (PNM)-based intervention studies in improving academic performance: A meta-analysis study. *Chemistry Education Research and Practice, 24*(4), 1221–1236. https://doi.org/10.1039/D3RP00083A

Center for Curriculum and Textbooks. (2022). *Science learning outcomes (Phase D) for junior high school*. Ministry of Education, Culture, Research, and Technology.

Chandrasegaran, A. L., Treagust, D. F., & Mocerino, M. (2007). The development of a two-tier multiple-choice diagnostic instrument for evaluating secondary school students' ability to describe and explain chemical reactions using multiple levels of representation. *Chemistry Education Research and Practice, 8*(3), 293–307. https://doi.org/10.1039/B7RP90006F

Chandrasegaran, A. L., Treagust, D. F., & Mocerino, M. (2011). Facilitating high school students' use of multiple representations to describe and explain simple chemical reactions. *Teaching Science, 57*(3), 13–20.

Chen, X., Goes, L. F. de, Treagust, D. F., & Eilks, I. (2019). An analysis of the visual representation of redox reactions in secondary chemistry textbooks from different Chinese communities. *Education Sciences, 9*(3), 180. https://doi.org/10.3390/educsci9030180

Chiu, M. H. (2007). A national survey of students' conceptions of chemistry in Taiwan. *International Journal of Science Education, 29*(4), 421–452. https://doi.org/10.1080/09500690601080736

Chittleborough, G., & Treagust, D. F. (2007). The modeling abilities of non-major chemistry students and their understanding of the sub-microscopic level. *Chemistry Education Research and Practice, 8*(3), 274–292. https://doi.org/10.1039/B6RP90035F

Cochran, W. G. (1954). Some methods for strengthening the common χ^2 tests. *Biometrics, 10*(4), 417–451. https://doi.org/10.2307/3001616

Coll, R. K., & Treagust, D. F. (2003). Learners' mental models of chemical bonding. *International Journal of Science Education, 25*(11), 1353–1368. https://doi.org/10.1080/0950069032000052063

Driver, R., Guesne, E., & Tiberghien, A. (1985). *Children's ideas in science*. Open University Press.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5–12. https://doi.org/10.3102/0013189X023007005

Duit, R., & Treagust, D. F. (2012). Conceptual change: Still a powerful framework for improving the practice of science instruction. *International Journal of Science Education, 34*(1), 1–42. https://doi.org/10.1080/09500693.2011.620379

Ebbing, D. D., & Gammon, S. D. (2009). *General chemistry* (9th ed.). Houghton Mifflin.

Gilbert, J. K. (2005). Visualization: A metacognitive skill in science and science education. In J. K. Gilbert (Ed.), *Visualization in science education* (Vol. 1, pp. 9–27). Springer.

Gilbert, J. K., & Treagust, D. F. (Eds.). (2009). *Multiple representations in chemical education*. Springer.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate data analysis* (8th ed.). Cengage Learning.

Hamerská, L., Matěcha, T., Tóthová, M., & Rusek, M. (2024). Between symbols and particles: Investigating the complexity of learning chemical equations. *Education Sciences, 14*(6), 570.

Harrison, A. G., & Treagust, D. F. (2002). The particulate nature of matter: Challenges in understanding the submicroscopic world. In J. K. Gilbert et al. (Eds.), *Chemical education: Towards research-based practice* (pp. 189–212). Kluwer Academic.

Johnstone, A. H. (1991). Why is science difficult to learn? Things are rarely what they seem. *Journal of Computer Assisted Learning, 7*(2), 75–83. https://doi.org/10.1111/j.1365-2729.1991.tb00230.x

Kelly, R. M., Barrera, J. H., & Mohamed, S. C. (2010). An analysis of undergraduate general chemistry students' misconceptions of the submicroscopic level of representing matter. *Journal of Chemical Education, 87*(1), 91–97.

Levy, J. (2024). An augmented reality application for understanding 3D molecular models (MoleculAR). *Journal of Chemical Education*. https://doi.org/10.1021/acs.jchemed.4c00312

Lee, O., Eichinger, D. C., Andersen, C. W., Berkheimer, G. D., & Blakeslee, T. D. (1993). Changing middle school students' conception of matter and molecules. *Journal of Research in Science Teaching, 30*(3), 249–269.

Malone, L. J., & Dolter, T. O. (2010). *Basic concepts of chemistry* (8th ed.). Wiley.

Mandrekar, J. N. (2011). Measures of interrater agreement. *Journal of Thoracic Oncology, 6*(1), 6–7. https://doi.org/10.1097/JTO.0b013e318200fca4

Messick, S. (1995). Validity of psychological assessment: Validation of inferences from persons' responses and performances as scientific inquiry into score meaning. *American Psychologist, 50*(9), 741–749. https://doi.org/10.1037/0003-066X.50.9.741

Ministry of Education and Culture of the Republic of Indonesia. (2017). *Core and basic competencies for junior high school (Revised 2017)*. Ministry of Education and Culture.
Moju, M., Taylor, L., & Iweuno, B. N. (2025). Tackling the challenges of chemical representations through sensemaking practices in chemistry education. *Discover Education, 4*, 352.
Naah, B. M., & Sanger, M. J. (2012). Investigating high school students' mental models of solution chemistry concepts. *Journal of Chemical Education, 89*(3), 307–313. https://doi.org/10.1021/ed100622d
Novick, S., & Nussbaum, J. (1981). Pupils' understanding of the particulate nature of matter: A cross-age study. *Science Education, 65*(2), 187–196. https://doi.org/10.1002/sce.3730650207
OECD. (2019). *PISA 2018 results: What students know and can do*. OECD Publishing.
Özmen, H. (2013). Preservice science teachers' conceptions of the particulate nature of matter. *International Journal of Environmental Science Education, 8*(3), 461–480.
Paçacı, Ç. (2022). *Effectiveness of conceptual change strategies in science education: A meta-analysis* [Master's thesis, Middle East Technical University]. Middle East Technical University Institutional Repository.
Peperkorn, Y., et al. (2024). Comparing drawing tasks and simulation-based learning. *Research in Practice*. https://doi.org/10.1039/D4RP00089F
Petrucci, R. H., Herring, F. G., Madura, J. D., & Bissonnette, C. (2017). *General chemistry: Principles and modern applications* (11th ed.). Pearson.
Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211–227.
Radzuan, N. A., & Hanri, M. (2024). Science students' misconceptions of basic concepts of chemistry on matter and its particulate properties. *International Journal of Academic Research in Progressive Education and Development, 13*(1), 112–127. https://doi.org/10.6007/IJARPED/v13-i1/20075
Retnawati, H. (2016). *Quantitative analysis of research instruments*. Parama Publishing.
Sanchez, J. M. P. (2025). Multiple representations framework in technology acceptance: A structural equation modeling of science educational videos in teaching and learning redox reactions. *STEM Education, 5*(5), 855–881.
Sidauruk, S. (2002). Students' conceptions of gas. *Journal of Mathematics and Natural Sciences Education, 3*(1), 45–52.
Stammes, H. (2025). Drawing meaning from student-generated drawings. *Research in Practice*. https://doi.org/10.1039/D5RP00045A
Stojanovska, M., Malkovska, S., & Jovanovski, T. (2017). Students' representations of the structure of matter. *Chemistry Education Research and Practice, 18*(2), 365–374. https://doi.org/10.1039/C6RP00231E
Suparno, P. (1997). Constructivist philosophy education. Yogyakarta Kanisius Publisher.
Taber, K. S. (2002). *Chemical misconceptions: Prevention, diagnosis and cure* (Vol. 1). Royal Society of Chemistry.
Wu, M.-Y., & Yezierski, E. J. (2022). Secondary chemistry teacher learning: Precursors for and mechanisms of pedagogical conceptual change. *Chemistry Education Research and Practice, 23*(4), 736–750. https://doi.org/10.1039/D2RP00012C