Educación Química

High School Students' Conceptual Understanding About Gas Nature and Properties in Iran

Comprensión conceptual de los estudiantes de bachillerato sobre la naturaleza y las propiedades del gas en Irán

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Resumen

Las concepciones erróneas en ciencia representan un desafío tanto para estudiantes como para docentes, ya que muchos alumnos aceptan como verdaderos los conceptos presentados por sus profesores y libros de texto, aunque estos también pueden ser fuente de malentendidos. Este estudio tuvo como objetivo identificar las percepciones de los estudiantes sobre el comportamiento y las propiedades de los gases mediante una prueba diagnóstica de 60 minutos. La muestra incluyó a 142 estudiantes de décimo grado en una escuela para el desarrollo de talentos excepcionales en Irán. La prueba, compuesta por seis preguntas de opción múltiple y tres preguntas abiertas, fue validada por expertos en química y mostró una alta concordancia interevaluador. Se evaluó la comprensión de los estudiantes sobre las fuerzas interpartículas en la fase gaseosa, la relación entre la energía cinética y la presión del gas, así como la naturaleza y las interacciones de las partículas gaseosas. Los resultados indicaron que la mayoría de los estudiantes respondieron incorrectamente. El análisis de sus explicaciones reveló la presencia de múltiples concepciones erróneas, especialmente en conceptos a nivel particulado. Además, estas concepciones pueden considerarse una forma de conocimiento previo arraigado en un marco lógico y justificativo, aunque no siempre alineado con el conocimiento científico establecido.

Palabras clave: conceptos erróneos en ciencia, educación en química, comprensión de los gases, dificultades de aprendizaje, enseñanza de ciencias.

Abstract

Misconceptions in science pose a significant challenge for both students and teachers, as many students accept what their teachers say as true, and textbooks can also contribute to misunderstandings. This study aimed to identify students' perceptions of gas behavior and properties through a 60-minute diagnostic test. The sample consisted of 142 10th-grade students from a school for developing exceptional talents in Iran. The test, comprising six multiple-choice and three open-ended questions, was validated by chemistry experts and demonstrated high inter-rater reliability. It assessed students' understanding of interparticle forces in the gas phase, the relationship between kinetic energy and gas pressure, and the nature and interactions of gas particles. The results showed that most students answered the questions incorrectly. Analyzing their explanations revealed several misconceptions, particularly regarding particulate-level concepts. Furthermore, misconceptions can be considered a form of prior knowledge, embedded within a framework of logic and justification, even if they contradict established scientific understanding.

Keywords : science misconceptions, chemistry education, gas behavior understanding, learning difficulties, science teaching.

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Introduction

Understanding scientific concepts presents significant challenges for students, often leading to widespread misconceptions that hinder effective learning. To address this issue, science education researchers have focused on identifying and correcting these misconceptions to improve educational outcomes (Günter & Alpat, 2019; Opitz et al., 2019; Preston, 2019). Shehab and BouJaoude (2017) define misconceptions as instances where students' preexisting knowledge does not align with scientific concepts, leading them to integrate new information in an incomplete or inaccurate manner before achieving a deeper conceptual change. This process aligns with Ausubel's advance organizer theory, which emphasizes linking new information to existing cognitive structures for meaningful learning, as well as with the cognitive construction pyramid, which highlights the hierarchical organization of knowledge (Martins, Baptista, & Arroio, 2021; Ribeiro, Passos, & Salgado, 2022).

The origins of misconceptions are diverse and include sources such as textbooks, teachers, and students themselves (Habiddin et al., 2022; Lima & Passos, 2023). Textbooks may perpetuate misunderstandings through oversimplified explanations, ambiguous language, or inaccurate representations of concepts. Teachers, often regarded as authoritative sources, may inadvertently reinforce these misconceptions by relying on traditional teaching methods that lack clarity or fail to address alternative explanations (Jusniar et al., 2021; Lamoureux & Ogilvie, 2022). Students, in turn, tend to accept teachers' statements as true due to their perception of them as experts. Additionally, Nofitasari and Sihombing (2017) argue that misconceptions stem from students' learning difficulties, which may arise from both internal and external factors. Internally, a lack of interest and motivation can hinder comprehension, while externally, the use of limited instructional strategies and insufficient teaching resources may contribute to misunderstandings. Lackmann et al. (2017) further emphasize that student-related factors—such as associative thinking, prior conceptions, humanistic reasoning, cognitive development stages, intuition, and individual abilities—play a significant role in shaping misconceptions.

To effectively identify students' misconceptions, researchers employ diagnostic tools such as multiple-tier tests, open-ended questions, multiple-choice tests, and interviews (Ge, Unsworth, & Wang, 2017; Jusniar et al., 2020). Among these, multiple-choice tests are particularly useful for assessing cognitive processes and pinpointing specific areas of misunderstanding within a student cohort. These tests help differentiate between students who hold misconceptions, those who struggle to grasp the topic, and those who demonstrate a clear understanding. Carefully designed multiple-choice items can thus serve as a valuable tool for detecting and addressing students' misconceptions.

In chemistry education, the topic of gases and their behavior poses considerable learning challenges and is a frequent source of misconceptions (Meneses, Escobar, & Véliz, 2018). Despite its importance, research specifically addressing the perceptions and misconceptions of gifted students remains scarce (Yun & Park, 2018; Yaumi et al., 2020; Savasci-Acikalin, 2021). This study aims to assist chemistry teachers in identifying and correcting students' misconceptions, thereby enhancing instructional strategies through the implementation of a precise diagnostic tool. Additionally, this research aligns with the chemistry curricula of Iran, the U.S., and the UK, including the Next Generation Science Standards.

Studies indicate that students often misunderstand gas behavior due to insufficient emphasis on the particle nature of matter, leading to misconceptions about gas properties and processes (Hwang, 1995; Lin, Cheng, & Lawrenz, 2000; Senocak, Taskesenligil, & Sozbilir, 2007). Furthermore, research has demonstrated that conceptual understanding and problem-solving skills can be significantly improved through targeted teaching models and interactive simulations, such as the 5E learning model and PhET simulations (Yaumi et al., 2020; Atkinson, Croisant, & Bretz, 2021; Widarti, Rokhim, & Rahmaniyah, 2022; Winarni et al., 2022; Lutfi et al., 2023). These findings highlight the need for innovative instructional approaches to effectively address students' misconceptions regarding gas behavior.

The relevance of this research lies in its focus on students' conceptual understanding, a crucial factor for effective learning, as emphasized in various theoretical studies (Lin, Cheng, & Lawrenz, 2000; Kapıcı & Akcay, 2016; Bayuni, Sopandi, & Sujana, 2018; Opitz et al., 2019; Fuadi et al., 2020; Yaumi et al., 2020; Atkinson, Croisant, & Bretz, 2021). The objective of this study is to evaluate students' understanding of key chemistry concepts as presented in the newly approved Iranian chemistry textbook. This research is the first to examine students' comprehension of interparticle forces in the gas phase, the relationship between the kinetic energy of gas particles and gas pressure, the nature of gas particles and their potential interactions, and fundamental gas laws. Given the identified gaps in the literature, the study seeks to answer the following research questions:

1. Can diagnostic tests effectively reveal students' misconceptions about gases?
2. What are the most common misconceptions held by 10th-grade Iranian students regarding gases?

Methodology

The case study method is an effective approach for investigating misconceptions, as it allows for a detailed and comprehensive examination of specific misunderstandings within a clearly defined group (Günter & Alpat, 2019). In this study, a qualitative approach was used to explore high school students' understanding and beliefs about scientific concepts.

Population and Sample

The study sampled 142 out of 1,106 10th-grade students from Nowshahr City, Iran (2023-2024), using convenience sampling at a specialized talent school. Instruction was delivered through a traditional approach, focusing on gas laws, particle behavior, and the relationships between gas properties, as outlined in the Iranian 10th-grade national chemistry curriculum.

Research Instrument

A paper-based diagnostic test was used to assess students' perceptions of the nature, behavior, and properties of gases. The assessment was conducted after a four-week instructional period on the gas chapter. The test included six multiple-choice items, each offering two to five response options, designed to evaluate students' knowledge of the topic. These multiple-choice items were complemented by open-ended sections that required students to justify their answers.

To further elicit students' misconceptions, three additional open-ended questions were included, allowing for a more accurate identification of misunderstandings. The assessment was administered under controlled conditions, with a total duration of 60 minutes.

The test items were developed considering students' learning difficulties and common misconceptions identified in the literature (Stavy, 1991). Specifically, test items 1, 2, 8, and 9 were adapted from previous studies: Gegios, Salta, & Koinis (2017); Maulidah & Wulandari (2021); and Meli, Koliopoulos, & Lavidas (2021), respectively.

Data Analysis

The test questions covered key aspects of gas behavior, properties, and laws. The content validity of the test was established through expert review by two specialists in chemistry education. These experts assessed the test items based on content relevance, alignment with cognitive domain taxonomy and instructional objectives, and overall technical quality. The calculated kappa coefficient values (ranging from 0.685 to 0.923) indicated a high level of inter-rater agreement, confirming the test's reliability.

Student responses were categorized based on accuracy and completeness of explanations. Answers were classified into four groups:

1. **Correct Answers.** Responses that were entirely accurate and aligned with the learning objectives, providing detailed and clear explanations.
2. **Incorrect Answers.** Responses containing misconceptions or incorrect ideas about the topic.
3. **Incomplete Correct Answers.** Responses that were correct but lacked sufficient explanation.
4. **Blank or No Response.** Unanswered questions.

Additionally, students' reasoning was analyzed to identify potential causes of misconceptions. The research process was reviewed and approved by the school's ethics committee, and all participants provided free and informed consent.

Results and Discussion

Using Diagnostic Tests to Identify Misconceptions About Gases in 10th-Grade Students

The analysis focused on students' responses to questions related to gas behavior and properties, aiming to identify common misconceptions. Question 1 (Figure 1) assessed students' understanding of interparticle forces and whether they held misconceptions regarding these forces in different states of matter.

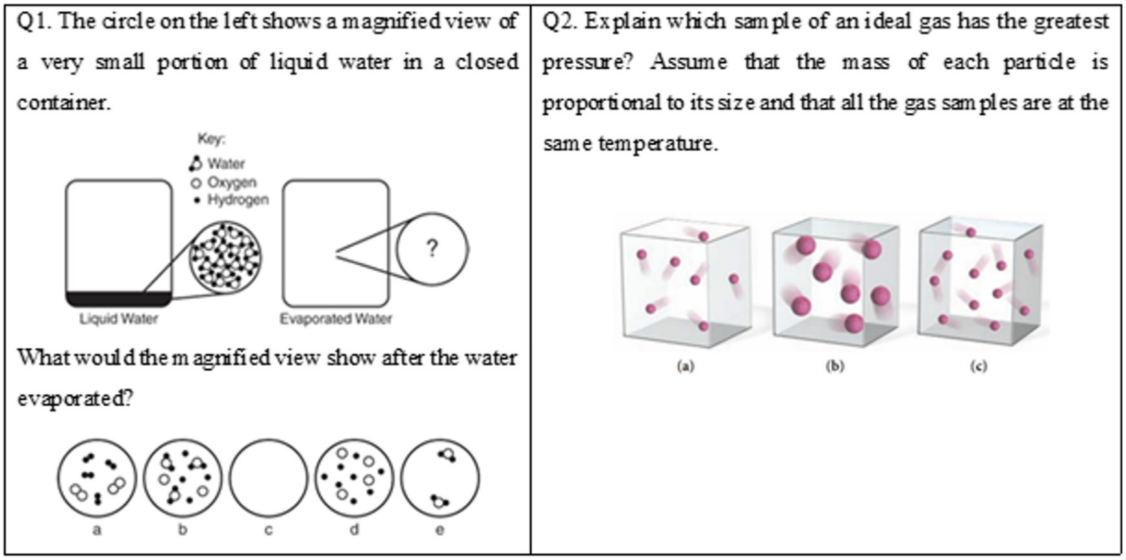


Figure 1. Question on the Evaporation Process and Factors Affecting Gas Pressure.

Students who chose answer (a) held the misconception that water molecules decompose into diatomic hydrogen and oxygen molecules during evaporation. The selection of option (d) by some students suggests they did not understand the distinction between intramolecular and intermolecular forces. Choices (b) and (d) indicate a misunderstanding of the water evaporation process, as they incorrectly suggest that either some (b) or all (d) of the covalent bonds within water molecules are broken during evaporation. Explanations in the open-ended section of Q1 show that nearly all students who selected the correct answer understood that "water evaporation is a physical change, meaning molecules separate without breaking their internal bonds."

Q2 (Figure 1) assessed students' understanding of the relationship between a particle's kinetic energy, mass, and velocity. According to the kinetic molecular theory, particles of different masses have the same average kinetic energy at a given temperature. In Q2, 63% of students selected the correct answer (c). However, one common misconception found in the open-ended responses was: "Item (c) is true because the particles are larger in size."

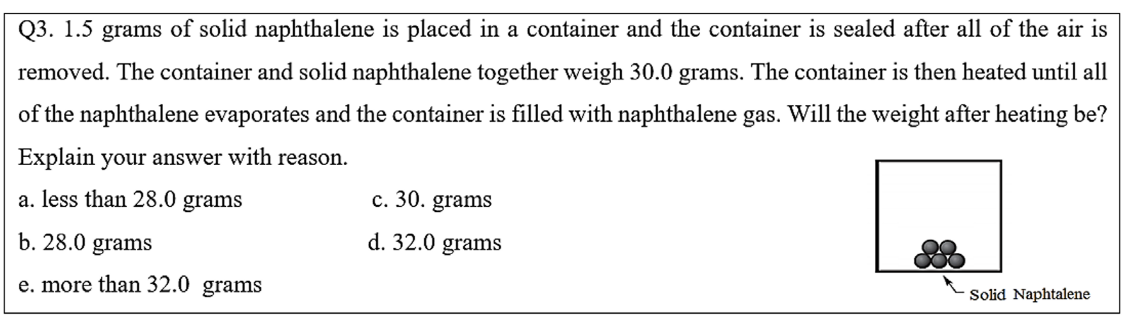


Figure 2. Question on the Sublimation Process.

Q3 (Figure 2) examined students' knowledge of the sublimation process and whether the mass of a substance changes when sublimation occurs in a closed container. In the multiple-choice section, a significant number of students (56%) answered incorrectly, suggesting that they believed matter loses mass when it converts to gas. Open-ended responses from these students included statements such as: "As the distance between molecules increases, the total mass decreases somewhat."

These findings suggest that many students believe the mass of a material in its gaseous state is lower than that of its solid form. This misconception may stem from the idea that because gas particles move more freely and occupy a larger space than solids, the total mass decreases.

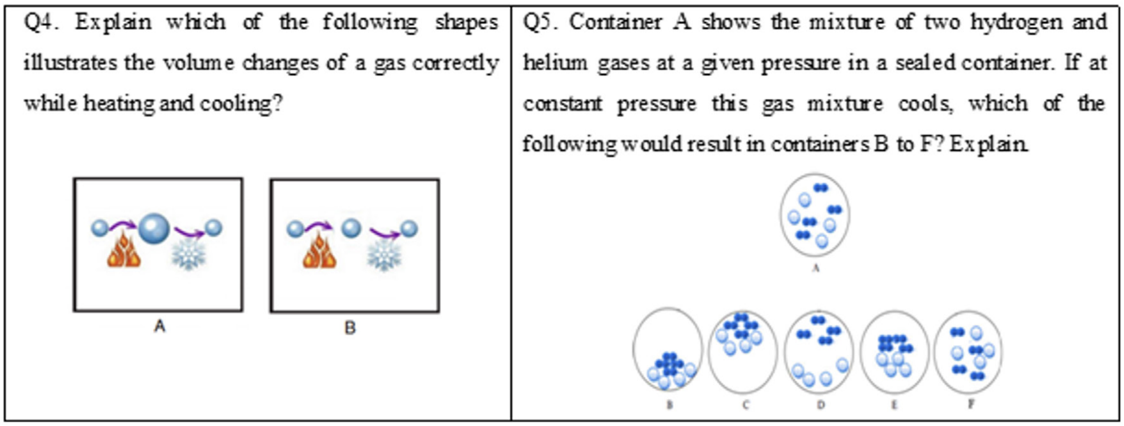


Figure 3. Question on Molecular Size and the Effects of Temperature Changes.

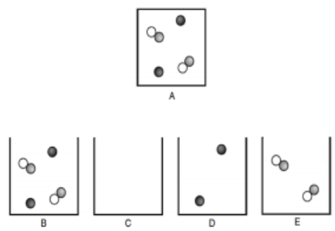
Q4 assessed students' understanding of the particulate nature of gases, as categorized by Fuadi et al. (2020). The study classified students' conceptions into four categories: (1) particulate nature, which includes size, volume, and weight; (2) behavior patterns, such as the random movement of gases; (3) interactions among particle components; and (4) interactions based on particle behavior.

Based on these categories, Q4 (Figure 3) tested students' comprehension of the particulate nature of matter. While 40% of students answered correctly, 57% selected incorrect responses. Many students who answered incorrectly initially recognized that temperature affects molecular behavior but misinterpreted its impact on molecular size. This confusion likely arises from the mistaken belief that energy changes alter the intrinsic properties of molecules.

Q5 (Figure 3) evaluated students' understanding of the second, third, and fourth categories proposed by Fuadi et al. (2020). Some students believed that when gas molecules cool, they accumulate at the bottom of the container (item b), attributing this to reduced particle movement due to lower temperatures. Others assumed that heavier gases settle in lower areas while lighter gases rise (item d).

Q6 (Figure 4) examined students' understanding of gas movement and penetration between a container and its surroundings. A total of 42%, 28%, and 7% of students selected answers (b), (d), and (e), respectively. Those who chose these options viewed gas particles as volatile entities that are forced into a container and remain inside only because the container is sealed. Their reasoning suggested a misconception that gas particles are inherently lightweight and will rise upon opening the lid, disregarding the fact that gas pressure inside and outside the container is equal.

Q6. Container A shows the mixture of two gases at a certain temperature and pressure in a sealed container. After reaching equilibrium, assuming that the environment outside container A includes only these two gases, which of the following containers B to E is completely incorrect to represent a mixture of these two gases? At the same pressure and temperature.



Q7. Container A contains ammonia gas (NH_3) and container B contains nitrogen monoxide gas (NO) at the same temperature and volume. Compare the pressure of the two gases in these containers with the reason.

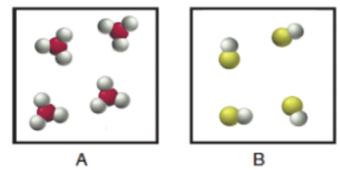


FIGURE 4. Question on Gas Behavior and Factors Affecting Gas Pressure.

Q7 (Figure 4) assessed students' understanding of gas pressure. Only 20% answered correctly with valid explanations, while 17% left the question unanswered and 63% selected incorrect responses. Some of the misconceptions included:

- *"Pgas = ρgh, in this equation g is constant, h is constant, thus* $\rho_A > \rho_B$*, as a result of* $P_A > P_B$ *because the number of atoms in container A is greater".*
- *"*$P_B > P_A$ *because nitrogen monoxide mass is higher than ammonia".*

Q8. The Figure below represents a sample of gas at a pressure of 1 atm, a volume of 1 L, and a temperature of 25°C. Draw a similar picture showing what would happen to the sample if the volume was reduced to 0.5 L and the temperature was increased to 250°C. What would happen to the pressure?

Q9. Each of the following processes caused the gas volume to double, as shown, for each process, state how the remaining gas variable changed or that it remained fixed.

(a) *T* doubles at fixed *P*.

(b) *T* and *n* are fixed.

(c) At fixed *T*, the reaction is $CD_2(g) \rightarrow C(g) + D_2(g)$.

(d) At fixed *P*, the reaction is $A_2(g) + B_2(g) \rightarrow 2AB(g)$.

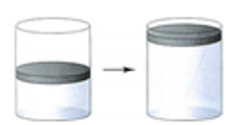


FIGURE 5. Question on Gas Laws.

Q8 and Q9 (Figure 5) were designed to assess whether students had correctly learned gas law concepts. A striking 83% of students did not attempt to answer the questions, while those who did provided incomplete responses. One student explained case (b) (where temperature and the number of particles remain constant) as follows: "Pressure increased, and then the volume increased." This response suggests a misunderstanding of Boyle's Law, possibly due to the incorrect assumption that instead of increasing external pressure, internal gas pressure increases.

Additionally, 3% of students responded to case (b) with: "Volume or pressure will double." This indicates an incomplete understanding of Boyle's Law, as they failed to recognize the inverse relationship between volume and pressure.

Exploring the nature of misconceptions about gases among grade 10 Iranian students

Several major misconceptions were identified by analyzing students' responses to multiple-choice and open-ended questions. The study found 14 key misconceptions, as detailed in Table 1, which are discussed in the context of each question.

Table 1. Students' Misconceptions Related to Gases.

Category	Misconceptions	Question
Inter-particle forces	During water evaporation, covalent bonds in the molecules are broken.	Q1
Kinetic energy	Lighter gas molecules move more quickly. Therefore, they have a greater pressure than that of gas molecules with a higher mass at the same temperature.	Q2
Sublimation process	Solids lose some of their mass while sublimating and becoming gas.	Q3
Energy & mass changes	When gas molecules are heated, their energy rises, causing them to move more rapidly and increase in mass.	Q4
Particulate nature and particle interactions	Inside a sealed container, cooling the gas molecules causes the heavier particles to accumulate at the bottom, while the lighter particles rise to the top.	Q5
Movement and penetration of gases	A closed container holds gases, whereas an open container does not.	Q6
Concept of pressure	The shape, mass and atoms number of gas molecules and gas density affect the amount of gas pressure.	Q7
Concepts of gas laws	Gas particles don't spread evenly throughout a closed container.	Q8
	As pressure rises, the gas volume expands.	Q9

The findings of this study on the existence and origins of misunderstandings in teaching the nature of gases align with previous research by Stavy (1991), Hwang (1995), Lin, Cheng, and Lawrenz (2000), and Martinez et al. (2021). However, they contrast with the results reported by Benson, Wittrock, and Baur (1993) and Senocak, Taskesenligil, and Sozbilir (2007).

Conclusion

This study examined misconceptions about gases among 10th-grade students. To address the first research question, a sample of 142 students completed a multiple-choice test and particulate-level questions on gas behavior and properties. The results demonstrated that diagnostic tests are effective in identifying misconceptions about gases. These misconceptions often stem from students' prior knowledge and everyday experiences, which, while based on a logical system of reasoning, may contradict accepted scientific principles. Because these misunderstandings are deeply rooted in intuitive thinking, they tend to be highly resistant to change.

Regarding the second research question, everyday experiences influence students' initial understanding but often conflict with the counterintuitive principles of gas behavior taught in science. For example, individuals without a scientific background rarely conceptualize matter at a particulate level, leading to misconceptions such as associating energy changes with alterations in molecular mass or size. Likewise, the abstract and non-intuitive nature of ideal gases—including their uniform motion and pressure relationships—further complicates students' comprehension and their ability to integrate these concepts into their mental frameworks.

Recommendations

Beyond the conclusions of this study, researchers have the opportunity to explore various strategies to enhance students' conceptual understanding of the nature and properties of gases. Future studies should investigate the role of conceptual understanding in chemistry education and explore instructional techniques that improve students' ability to grasp abstract scientific concepts.

References

Atkinson, M. B., Croisant, M., & Bretz, S. L. (2021). Investigating first-year undergraduate chemistry students' reasoning with reaction coordinate diagrams when choosing among particulate-level reaction mechanisms. *Chemistry Education Research and Practice, 22*(1), 199-213. https://doi.org/10.1039/D0RP00193G

Bayuni, T. C., Sopandi, W., & Sujana, A. (2018). Identification misconception of primary school teacher education students in changes of matters using a five-tier diagnostic test. *Journal of Physics: Conference Series, 1013*, 012086. https://doi.org/10.1088/1742-6596/1013/1/012086

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.3660300607

Fuadi, F. N., Sopandi, W., Priscylio, G., Hamdu, G., & Mustikasari, L. (2020). Students' conceptual changes on the air pressure learning using predict-observe-explain strategy [Misconception; conception changes; and POE strategy]. *Mimbar Sekolah Dasar, 7*(1), 16. https://doi.org/10.53400/mimbar-sd.v7i1.22457

Ge, Y.-P., Unsworth, L., & Wang, K.-H. (2017). The effects of explicit visual cues in reading biological diagrams. *International Journal of Science Education, 39*(5), 605-626. https://doi.org/10.1080/09500693.2017.1297549

Gegios, T., Salta, K., & Koinis, S. (2017). Investigating high-school chemical kinetics: The Greek chemistry textbook and students' difficulties. *Chemistry Education Research and Practice, 18*(1), 151-168. https://doi.org/10.1039/C6RP00192K

Günter, T., & Alpat, S. K. (2019). What is the effect of case-based learning on the academic achievement of students on the topic of "biochemical oxygen demand"? *Research in Science Education, 49*(6), 1707-1733. https://doi.org/10.1007/s11165-017-9672-9

Habiddin, H., Akbar, D., Husniah, I., & Luna, P. (2022). Uncovering students' understanding: Evidence for the teaching of acid-base properties of salt solution. *Educación Química, 33*, 64. https://doi.org/10.22201/fq.18708404e.2022.1.79488

Hwang, G.-J. (1995). Knowledge acquisition for fuzzy expert systems. *International Journal of Intelligent Systems, 10*(6), 541-560. https://doi.org/10.1002/int.4550100602

Jusniar, J., Effendy, E., Budiasih, E., & Sutrisno, S. (2020). Developing a three-tier diagnostic instrument on chemical equilibrium (TT-DICE). *Educación Química, 31*, 84. https://doi.org/10.22201/fq.18708404e.2020.3.72133

Jusniar, J., Effendy, E., Budiasih, E., & Sutrisno, S. (2021). The effectiveness of the "EMBE-R" learning strategy in preventing students' misconceptions in chemical equilibrium. *Educación Química, 32*, 53. https://doi.org/10.22201/fq.18708404e.2021.2.75566

Kapıcı, H., & Akcay, H. (2016). Particulate nature of matter misconceptions held by middle and high school students in Turkey. *European Journal of Education Studies, 2*(8). https://doi.org/10.5281/zenodo.163547

Lackmann, A., Mahr, C., Schowalter, M., Fitzek, L., Weissmüller, J., Rosenauer, A., & Wittstock, A. (2017). A comparative study of alcohol oxidation over nanoporous gold in gas and liquid phase. *Journal of Catalysis, 353*, 99-106. https://doi.org/10.1016/j.jcat.2017.07.008

Lamoureux, G., & Ogilvie, J. (2022). New directions in teaching introductory and organic chemistry. *Educación Química, 33*, 167. https://doi.org/10.22201/fq.18708404e.2022.3.80759

Lima, F., & Passos, C. (2023). A training action for chemistry and science teachers: Contribution of problem-solving activities to inclusive education. *Educación Química, 34*, 102-117. https://doi.org/10.22201/fq.18708404e.2023.3.83078

Lin, H.-S., Cheng, H.-J., & Lawrenz, F. (2000). The assessment of students and teachers' understanding of gas laws. *Journal of Chemical Education, 77*(2), 235. https://doi.org/10.1021/ed077p235

Lutfi, A., Hidayah, R., Aftinia, F., & Ipmawati, N. (2023). House of chemistry as a hydrocarbon learning media for high school students. *Educación Química, 34*, 176-187. https://doi.org/10.22201/fq.18708404e.2023.1.82798

Martinez, B. L., Sweeder, R. D., VandenPlas, J. R., & Herrington, D. G. (2021). Improving conceptual understanding of gas behavior through the use of screencasts and simulations. *International Journal of STEM Education, 8*(1), 5. https://doi.org/10.1186/s40594-020-00261-0

Martins, I., Baptista, M., & Arroio, A. (2021). Students' cognitive structures about the copper cycle. *Educación Química, 32*, 34. https://doi.org/10.22201/fq.18708404e.2021.5.78699

Maulidah, N., & Wulandari, F. (2021). Literature study: Improving understanding of science concepts using science comics for elementary school students. *Jurnal Penelitian Pendidikan IPA, 7*(1), 80-86. https://doi.org/10.29303/jppipa.v7i1.509

Meli, K., Koliopoulos, D., & Lavidas, K. (2021). A model-based constructivist approach for bridging qualitative and quantitative aspects in teaching and learning the first law of thermodynamics. *Science & Education.*https://doi.org/10.1007/s11191-021-00262-7

Meneses, A., Escobar, J.-P., & Véliz, S. (2018). The effects of multimodal texts on science reading comprehension in Chilean fifth-graders: Text scaffolding and comprehension skills. *International Journal of Science Education, 40*(18), 2226-2244. https://doi.org/10.1080/09500693.2018.1527472

Nofitasari, I., & Sihombing, Y. (2017). Deskripsi kesulitan belajar peserta didik dan faktor penyebabnya dalam memahami materi listrik dinamis kelas X SMA Negeri 2 Bengkayang. *Jurnal Penelitian Fisika dan Aplikasinya (JPFA), 7*(1), 44-53. https://doi.org/10.26740/jpfa.v7n1.p44-53

Opitz, S. T., Neumann, K., Bernholt, S., & Harms, U. (2019). Students' energy understanding across biology, chemistry, and physics contexts. *Research in Science Education, 49*(2), 521-541. https://doi.org/10.1007/s11165-017-9632-4

Preston, C. M. (2019). Effect of a diagram on primary students' understanding about electric circuits. *Research in Science Education, 49*(5), 1433-1456. https://doi.org/10.1007/s11165-017-9662-y

Ribeiro, D., Passos, C., & Salgado, T. (2022). Problem-solving methodology in chemical technician education. *Educación Química, 33*, 106. https://doi.org/10.22201/fq.18708404e.2022.2.79856

Savasci-Acikalin, F. (2021). How middle school students represent phase change and interpret textbook representations: A comparison of student and textbook representations. *Research in Science Education, 51*(6), 1651-1685. https://doi.org/10.1007/s11165-019-9834-z

Senocak, E., Taskesenligil, Y., & Sozbilir, M. (2007). A study on teaching gases to prospective primary science teachers through problem-based learning. *Research in Science Education, 37*, 279-290. https://doi.org/10.1007/s11165-006-9026-5

Shehab, S. S., & BouJaoude, S. (2017). Analysis of the chemical representations in secondary Lebanese chemistry textbooks. *International Journal of Science and Mathematics Education, 15*(5), 797-816. https://doi.org/10.1007/s10763-016-9720-3

Stavy, R. (1991). Using analogy to overcome misconceptions about conservation of matter. *Journal of Research in Science Teaching, 28*(4), 305-313. https://doi.org/10.1002/tea.3660280404

Widarti, H., Rokhim, D., & Rahmaniyah, N. (2022). Multiple representation-based mobile apps with learning cycle 7E model on colligative properties of solutions. *Educación Química, 33*, 115-126. https://doi.org/10.22201/fq.18708404e.2022.3.80540

Winarni, S., Effendy, E., Budiasih, E., & Wonorahardjo, S. (2022). Constructing 'concept approval strategy,' a chemistry learning idea to prevent misconceptions. *Educación Química, 33*, 159. https://doi.org/10.22201/fq.18708404e.2022.2.79841

Yaumi, M. R., Sutopo, Zulaikah, S., & Sulur. (2020). Improving students' conceptual understanding on kinetic theory of gas through modeling instruction. *AIP Conference Proceedings, 2215*(1), 030025. https://doi.org/10.1063/5.0003648

Yun, E., & Park, Y. (2018). Extraction of scientific semantic networks from science textbooks and comparison with science teachers' spoken language by text network analysis. *International Journal of Science Education, 40*(17), 2118-2136. https://doi.org/10.1080/09500693.2018.1521536