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Identifying misconceptions in students' understanding of the concept of physical and chemical change with open-ended questions

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ABSTRACT

This study aims to identify misconceptions in students' understanding of physical and chemical changes using objective instruments in the form of open-ended descriptions and reasons. Chemistry is a science that underlies knowledge of the structure and changes of matter through three levels of representation: macroscopic, submicroscopic, and symbolic. However, students' limited ability to connect these levels of representation often leads to misconceptions that can hinder understanding of more complex concepts in the future. This study used a qualitative descriptive approach with 21 grade 10 students at a high school in Yogyakarta as subjects. The research instrument consisted of 5 open-ended questions and reasons used to categorize students' mindsets into understanding the concept, misconceptions, and not understanding the concept. The study found misconceptions across various subconcepts, including the assumption that chemical changes are absolutely unidirectional (irreversible) and the inability to distinguish particle interactions during salt dissolution and magnesium combustion. The main factors causing these misconceptions are incomplete preconceptions, incorrect reasoning, and a lack of in-depth understanding at the submicroscopic level. This placement emphasizes strengthening knowledge of basic concepts and integrating levels of chemical representation to improve students' thinking patterns.

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1. INTRODUCTION

Chemistry is a branch of science that serves as a foundation for understanding the structure, composition, and properties of solutions and changes in matter. The scope of chemistry is quite broad and often requires critical thinking, which can make it difficult for students to understand the subject. Chemical representations are generally divided into three levels: macroscopic, submicroscopic, and symbolic (Iqbal et al., 2020). Learning strategies that incorporate these three chemical representations are considered effective in overcoming students' difficulties in understanding chemical concepts and improving their learning success. However, research by Zidny et al. (2015) indicates that students' ability to translate between levels of representation remains low. These findings suggest that students' lack of understanding of chemical materials can lead to misconceptions and misunderstandings when interpreting chemical concepts.

Misconceptions are students' incorrect or different understandings of scientific concepts. Misconceptions are typically caused by several factors, such as teacher misconceptions when explaining learning materials, incomplete student understanding, incomplete learning resources (textbooks or practice questions), and inappropriate teaching methods (Rohmah et al., 2023). In chemistry learning, misconceptions often occur because students struggle to connect their prior knowledge (preconceptions) with new material, engage in faulty reasoning, and lack sufficient interest and motivation to learn. Persistent misconceptions among students will impact the new concepts they will learn in the future. Therefore, scientifically unacceptable concepts, if not corrected through a process of "unlearning," will continue to hinder the development of more complex conceptual understanding in the future (Kismiati & Hutasoit, 2024).

Changes in matter are a concept in chemistry that can lead to misconceptions among students. Changes in matter are generally divided into two types: chemical changes and physical changes (Junarti et al., 2018). This topic was chosen because the fundamental nature of physical and chemical changes can lead to conceptual misunderstandings, as students struggle to distinguish between irreversible and reversible changes. A physical change is a transformation or change that occurs only in physical form, such as size, shape, or form, without producing a new substance and without the ability to return to its original state (Rahmadhani et al., 2023). Physical changes are often called reversible because they allow a substance to return to its original state. On the other hand, chemical changes involve chemical reactions that form a new substance with different properties from the original substance. Chemical changes are often referred to as irreversible, meaning they cannot be reversed. They are caused by the breaking of chemical bonds and the formation of new substances with different molecular compositions.

Physical and chemical changes can lead to misconceptions if students do not understand the basic concepts of these changes. A contributing factor to misconceptions in this material is students' prior knowledge or preconceptions, which often assume that all changes involving heating are physical changes, such as the dissolution of salt and the combustion of magnesium (Dewanti & Hidayati, 2018). This misconception stems from the lack of in-depth teacher explanations at the submicroscopic level during physical and chemical changes, making it difficult for students to differentiate between the types of changes.

Based on this explanation, research is needed to identify students' misconceptions about physical and chemical changes using open-ended essay questions and their rationales. The primary focus of this research is to determine the extent of students' conceptual understanding and to explore the factors contributing to misconceptions in this material. By combining open-ended answers and student argumentation, it is hoped that a comprehensive picture of students' thinking patterns can be accurately mapped.

2. METHODS

This type of research uses a descriptive qualitative approach. According to Creswell & Creswell (2018), descriptive qualitative research is used to explore and understand the meaning contained in social problems through an individual or group perspective. This research was conducted to determine the location of students' misconceptions regarding the material on physical and chemical changes. This research was conducted at a high school in the Special Region of Yogyakarta. Purposive sampling was applied to reveal their understanding of the chemical change concept. The primary consideration is that the student's achievement in the school subject is lower than that of other schools in the Yogyakarta region. The subjects of this research were all 21 students of class X MIPA. This research used a valid and reliable test instrument consisting of open-ended questions with reasons. This instrument was validated by Keith Taber in 2002 and published in the Royal Society of Chemistry (RSC) book titled Chemical Misconceptions Prevention, Diagnosis, and Cure. Five questions are used to reveal students' misconceptions.

Regarding language validation, the original instrument was translated into Bahasa, and some experts confirmed that the meanings in both languages were similar. The employed test from Taber (2002) is specified on the material of physical and chemical changes. The next step was to tabulate the data from student answers, identifying the number of misconceptions for each question.

3. RESULTS AND DISCUSSIONS

Based on the test results, it is necessary to determine students' conceptual understanding to identify misconceptions. Students' levels of understanding are classified into three categories, as shown in Table 1 (Abraham et al., 1992):

Table 1. Misconception criteria

No	Level of Understanding	Criteria for Assessment
1	Don't Understand the Concept	No answer: answer but not related to the question and/or the answer is unclear.
2	Misconceptions	Answering but the explanation given is incorrect or illogical; the answer shows that there are concepts that are mastered, but there are statements that indicate misconceptions.

No	Level of Understanding	Criteria for Assessment
3	Understand the Concept	The answer shows that the concept is mastered correctly; the answer shows that only part of the concept is understood without misconceptions.

The data used in this study were obtained from students' answers to 5 open descriptive questions about physical and chemical changes, along with their reasons, yielding the data presented in Table 2.

Table 2. Tabulation of student answer data

Question Number	Total Correct Answers	Misconceptions	Not Understanding	Total Overall Students
1	20	1	0	21
2	17	3	0	21
3	19	2	0	21
4	18	2	1	21
5	16	2	3	21

Based on the data in the Table 3, there is one misconception regarding the sub-concept of understanding physical change. The student assumed that physical change is "a change that occurs in a substance." Analysis of the student's answers to this question shows that the answer given by the student was still very general and did not provide a more specific definition of physical change. The student assumed that the phenomenon of physical change is a unified whole. The student failed to realize that a chemical change is also a phenomenon of change that occurs in a substance. This misunderstanding stems from the student's lack of understanding of physical change, resulting in the answer being too broad and unable to explain the definition of physical change specifically.

The next misunderstanding concerns the sub-concept of understanding chemical change. Analysis of the student's answers to this sub-concept revealed three misconceptions. The first student answered that "chemical change is a change that occurs from the beginning and after the change, with differences, such as destruction." This answer is categorized as a misconception because it exemplifies "partial understanding" (Fitri et al., 2022). The student already has a correct chemical concept, but it is packaged in incorrect terminology, leading to misconceptions.

The misconceptions arise from the use of the words "different" and "destruction." The word "different" causes misconceptions because, not only in chemical changes, but also in physical changes, something that is "different" in appearance, but remains substantially the same. If students only use the indicator "different" without clear boundaries, they will categorize all changes in form (such as cutting wood or dissolving sugar) as chemical changes. The word "destruction" also causes misconceptions because, scientifically, matter is never destroyed or lost. Based on the law of conservation of mass, the number of atoms before and after a change is the same (Sihaloho et al., 2024). The use of the word "destruction" indicates that students only see changes from a macroscopic perspective, such as paper turning to ash, without understanding what happens at the microscopic level (Sukmawati, 2019). The first student's correct answer for number 2 was, "A chemical change is a change that produces a new substance due to the breaking or formation of chemical bonds, thereby changing the identity of the constituent particles."

Another misunderstanding in this subchapter is that two students answered, "A chemical change is a change that produces a new substance with properties different from the original substance and whose properties cannot be reversed." This answer is categorized as a misconception because it demonstrates mastery of the concept, but there is a statement that demonstrates a misconception, namely the statement "its properties cannot be reversed." These students assume that all chemical changes are unidirectional (permanent) and irreversible. This misconception can occur because students often conclude from simple examples in everyday life, such as paper burning to ash. In advanced chemistry, many chemical reactions are reversible. This means that the substances produced (products) can react back to form the original substances (reactants) under certain conditions. An example is the Haber process for producing ammonia. Nitrogen and hydrogen gases combine to form ammonia, but ammonia can decompose back into nitrogen and hydrogen in the same container (Mu'minin et al., 2020). The answer the second and third students should have given for question 2 is "A chemical change is a change that produces a new substance with properties different from the original substance and whose properties can be restored to their original form."

Regarding the concept of physical change when liquid nitrogen is frozen, two students had misconceptions in their answer, and one student's answer required further discussion. The question is shown in Figure 1.

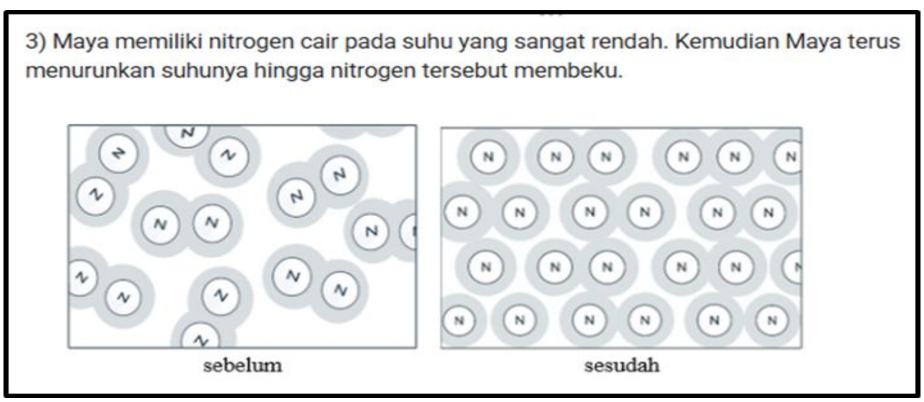

Figure 1. Questions on the concept of physical changes when liquid nitrogen is freezed

The first student correctly classified the freezing of nitrogen as a physical change, but the reasoning presented demonstrated a misconception of the term "chemical substance." At the macroscopic level, liquid nitrogen turns into a solid when the temperature is lowered. However, microscopically, the identity of the nitrogen particles does not change. This is in line with the statement Brown et al (2018) that "a physical change is a change in which the form of matter is altered but one substance is not transformed into another." The nitrogen molecules remained diatomic molecules of N_2 both before and after freezing, as seen in the particle arrangement, which only changed from random to more ordered. The student's misconception arose because they assumed physical changes did not involve chemical substances, whereas Chang & Goldsby (2013), asserted that "all matter is chemical in nature and consists of atoms or molecules." Thus, the correct reason nitrogen freezing is categorized as a physical change is that no new substances are formed and there is no change in molecular composition, but only a phase change due to changes in energy. In order, however, the same molecules remain before and after the change. Meanwhile, the second student classified the freezing of nitrogen as a chemical change, demonstrating a conceptual misconception in understanding the criteria for a chemical change. Macroscopically, the change from liquid to solid appears significant, but microscopically, there is no change in the structure or identity of the molecules. Chemical changes require the formation of a new substance, as stated by Zumdahl et al (2016) that "a chemical change involves a change in the composition of matter." In the freezing of nitrogen, the N_2 molecules before the change remain the same after the change, thus failing to meet this criterion. The student's logical error likely stems from equating a visually visible change with a chemical reaction. However, Gilbert (2018) explains that student misconceptions often arise because "students tend to focus on surface features rather than particulate-level explanations." Therefore, the freezing of nitrogen remains a physical change because it only involves changes in the arrangement and energy of particles, not the formation of a new substance.

The third student provided a correct explanation by linking the freezing of nitrogen to a decrease in molecular kinetic energy. At the macroscopic level, the nitrogen appears to freeze, while at the microscopic level, a decrease in temperature causes a decrease in the average kinetic energy of the N_2 molecules. Atkins & Paula (2018), explicitly state that "temperature is a measure of the average kinetic energy of the particles in a system." When the kinetic energy of molecules decreases, particle movement slows, so intermolecular forces become more dominant, and molecules arrange in more fixed positions, forming a solid phase. This explanation also aligns with the kinetic molecular theory, which states that phase changes occur due to energy changes, not changes in the substance's identity.

Another misunderstanding occurred regarding the concept of chemical change when magnesium burns. Two students misconstrued this sub-concept. The questions for this sub-concept are shown in Figure 2.

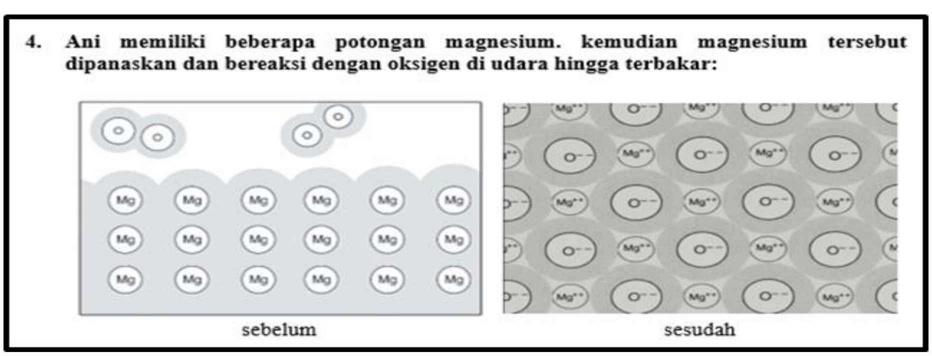

Figure 2. Chemical changes when magnesium is burned

The first student correctly answered the type of change, namely a chemical change. However, the student's reasoning contained a misconception. The student incorrectly assumed that chemical changes occur "because substances change their chemical identity." This was because the student assumed that oxygen acts as a change agent that can alter the chemical identity of magnesium during the combustion process. Conversely, the chemical identity of magnesium changes due to a reversible reaction that forms chemical bonds that produce a new compound, magnesium oxide (Alpionita & Astuti, 2015). The cause of this misunderstanding was the student's lack of understanding of the redox concept, as demonstrated by the student's failure to distinguish between components undergoing oxidation and reduction.

The second student correctly answered the type of change, namely a chemical change. However, the student's reasoning contained a misconception. The student's assumption that the chemical change was caused by "magnesium being exposed to air" was incorrect. The student's answer was a misconception because the student concluded that air was the primary cause of the chemical reaction without mentioning the component that acted as the primary reactant. In fact, the chemical change in magnesium occurs due to the combustion reaction required to activate oxidation with oxygen (Silberberg, 2020). Students tend to assume that exposure to air can trigger a direct reaction between magnesium and oxygen without any heating process. This student's opinion reflects a reversed understanding because they assume that air acts as the sole agent in the chemical change. This misunderstanding stems from a lack of understanding of chemical representations, where students understand the macroscopic level (burning in air) but fail to understand the submicroscopic level that occurs when solid magnesium reacts with O_2 after being heated.

The third student correctly answered the type of change, namely a chemical change. However, the student's reasoning was inaccurate, as the student assumed the chemical change was caused "by the chemical reaction of magnesium." This answer falls into the category of not understanding the concept because the student did not specifically explain the reaction that occurs in magnesium during the heating process. The student's answer should connect the magnesium oxidation process to the reaction equation that occurs, namely $2Mg + O_2 \rightarrow 2MgO$ as a result of exothermic combustion (Rahmiati et al., 2022). This conceptual error is caused by students tending to assume that answering "chemical reaction" is sufficient to answer the question. They lack understanding of combustion phenomena, such as the type of reaction that occurs, and their inability to relate it to the reaction equation or explain the primary role of oxygen.

One student's answer to the fourth question requires further discussion, where the student answered that chemical changes can occur "because magnesium is included in the alkaline earth metal group, which is known to be very chemically reactive." This statement indicates that the student is able to connect the combustion reaction of magnesium to its position in the alkaline earth metal group. Students can assume this because they understand the chemical reactivity of each element in the periodic table, especially magnesium, which has two valence electrons (ns^2), which are easily lost and form Mg^{2+} ions when reacting with oxygen. Magnesium belongs to the alkaline earth metal group, which tends to lose two electrons to achieve a stable electron configuration. This allows magnesium to undergo a rapid oxidation reaction with oxygen when heated, forming a new substance, MgO, or magnesium oxide.

Two students misunderstood the last question, and three students did not understand it. The questions on this sub-concept can be seen in the Figure 3.

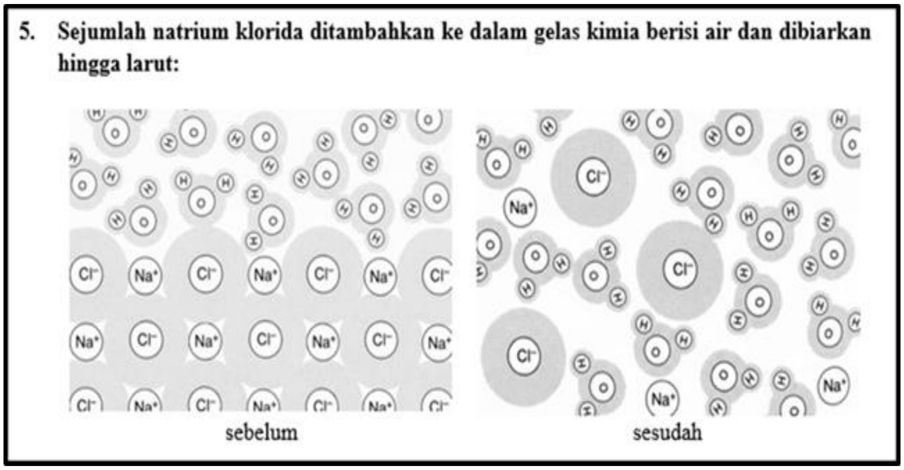

Figure 4. Changes that occur after nacl is dissolved in water

The first student's answer was incorrect, and the reasoning was also incorrect. The first student's misconception arose because the student thought that, because the ionic bond between Na and Cl was broken and a new interaction with water occurred, it must be a chemical reaction. This occurred because the student saw the solid salt grains disintegrate into ions surrounded by water. To the student, the change from solid to separate ions seemed like "the formation of something new," even though chemically, the two ions remained the same, Na and Cl ions dissolved in water (Rahma et al., 2025). The first student's correct answer was, "This is a physical change because no new substances are formed; the same particles (ions) remain before and after dissolution, and the salt can be recovered by evaporating the water."

The second student misconception arose because the answer was correct, but the reasoning was incorrect. The student simply rewrote the problem procedure in the reasoning column. Therefore, the student only explained "what" happened, not "why" it was a physical change. This occurred because the student may have simply memorized that "salt dissolving = physics," but did not understand the microscopic reasons behind it. When asked for a rationale, the student simply copied the sentence from the problem because he didn't know the supporting theory.

The other three students intuitively understood the concept of physical change, assuming that dissolved salt remains salt (it still tastes salty), so they correctly answered "physical change." However, when asked to explain their rationale scientifically, the students were hesitant or confused about how to describe the process of the NaCl crystal disappearing without mentioning the formation of something "new" (a solution). Students may have felt that a simple explanation like "just mixing" wasn't sufficient, but they weren't yet able to explain the process of ionic dissociation without making it sound like a chemical reaction.

4. CONCLUSIONS

Based on the research results, there are still misconceptions in students' understanding of the concept of physical and chemical changes, especially at the submicroscopic level. Although most students can classify the types of changes correctly (macroscopic), many still fail to provide appropriate scientific reasons, such as the assumption that all chemical changes are irreversible or the inability to distinguish molecular interactions during the dissolution of salt and the combustion of magnesium. The main factors causing these misconceptions are students' incomplete preconceptions, limited ability to connect various levels of chemical representation, and a lack of in-depth explanations of particle mechanisms during material changes. Identification through open-ended description instruments, and these reasons, demonstrate the importance of strengthening the understanding of fundamental concepts so that students do not experience obstacles in learning more complex chemistry materials in the future.

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