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ANALYSIS OF STUDENT MISCONCEPTIONS ON ATOMIC, MOLECULAR, AND IONIC MATTER: THE FOUNDATION OF DEVELOPING AUGMENTED REALITY AS AN INNOVATIVE SOLUTION

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ABSTRAK

Studi ini menganalisis miskonsepsi siswa pada materi atom, molekul, dan ion serta merancang solusi inovatif menggunakan Augmented Reality (AR). Materi tersebut menjadi dasar dalam ilmu kimia, namun pemahaman siswa seringkali kurang memadai dan miskonsepsi. Metode penelitian yang digunakan adalah deskriptif dengan pendekatan kualitatif dan kuantitatif. Instrumen three-tier diagnostic digunakan untuk mengidentifikasi miskonsepsi siswa, dilengkapi dengan wawancara guru. Sampel penelitian melibatkan 2 guru dan 61 siswa dari MA Nahdlatul Falah dan SMK Karya Budi di Kab. Bandung. Hasil analisis miskonsepsi menunjukkan pola miskonsepsi pada konsep atom, molekul, dan ion. Miskonsepsi melibatkan kesalahan factual, konseptual, dan metakognitif. Untuk mengatasi miskonsepsi, pengembangan instrumen three-tier diagnostic diperluas dengan pendekatan multi-representasi, mencakup representasi makroskopis, submikroskopis, dan simbolik. Solusi inovatif dalam bentuk AR dikembangkan sebagai media pembelajaran untuk meningkatkan pemahaman siswa. Elemen-elemen AR disusun berdasarkan analisis miskonsepsi, termasuk model 3D molekul senyawa, animasi struktur atom, dan simulasi interaktif rumus kimia. Penelitian ini memberikan kontribusi dalam merancang solusi pembelajaran inovatif untuk mengatasi miskonsepsi siswa. Augmented Reality menjadi alternatif yang potensial untuk meningkatkan representasi visual dalam pembelajaran kimia. Diharapkan pengembangan AR dapat menjadi panduan bagi pendidik dalam merancang strategi pembelajaran yang lebih efektif dan bermakna pada materi atom, molekul, dan ion.

ABSTRACT

The study analyzes students' misconceptions of atomic, molecular, and ionic matter and designs innovative solutions using Augmented Reality (AR). The material becomes basic in chemistry, but students' understanding is often inadequate and misconceptions. The research method used is descriptive with qualitative and quantitative approaches. A three-tier diagnostic instrument was used to identify student misconceptions, supplemented by teacher interviews. The research sample involved 2 teachers and 61 students from MA Nahdlatul Falah and SMK Karya Budi in Bandung District. The results of the misconception analysis show a pattern of misconceptions in the concepts of atoms, molecules, and ions. Misconceptions involve factual, conceptual, and metacognitive errors. To overcome misconceptions, the development of three-tier diagnostic instruments was expanded with a multi-representation approach, including macroscopic, submicroscopic, and symbolic representations. Innovative solutions in the form of AR are developed as learning media to increase student understanding. AR elements are organized based on analysis of misconceptions, including 3D models of compound molecules, animations of atomic structures, and interactive simulations of chemical formulas. This research contributes to designing innovative learning solutions to overcome student misconceptions. Augmented reality is a potential alternative to improving visual representation in chemistry learning. It is hoped that the development of AR can be a guide for educators in designing more effective and meaningful learning strategies on atomic, molecular, and ionic matter.

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INTRODUCTION

Each concept of science does not stand alone, but each concept is related to other concepts. All concepts together form a kind of network of knowledge in the human mind. Often, students only memorize concept definitions without paying attention to the relationship between one concept and other concepts. In this way, the new concept does not enter the network of concepts that already existed in students' minds before, but the concept stands alone without any relationship with other concepts. Students' mistakes in understanding the relationship between concepts often give rise to misconceptions.

Atoms, molecules, and ions are important basic concepts in chemistry. These concepts are the basis for understanding matter, material properties, and chemical reactions. However, students' understanding of these concepts is often inadequate, and they even experience misconceptions (Samborey & Kinya, 2019). Misconceptions can be caused by three things, including (1) daily experiences that are not in accordance with scientific concepts, (2) concepts that are formed due to a lack of understanding of prerequisite concepts, and (3) misconceptions that are transmitted from teachers through incorrect or inaccurate teaching (Yonata et al., 2020). Misconceptions cannot be generalized directly because the forms of misconception that occur can be different or the same. Therefore, an instrument is needed that can identify misconceptions.

Instruments for detecting misconceptions in students are not commonly used by educators to determine their students' level of understanding. In general, educators only use summative tests and formative tests to measure students' level of knowledge. One instrument that can be used to identify misconceptions is the three-tier. The three-tier test instrument is an instrument that was developed into three levels of questions, namely the first-tier in the form of ordinary multiple choices, the second tier in the form of reasons for the first-tier answer choices, and the third tier in the form of confirmation of confidence in the answers chosen at the first level and second level (Kirbulut & Geban, 2014). The three-tier instrument minimizes students' guessing by increasing the level of confidence in the third tier (Milenković et al., 2016). In this study, the use of three-tier diagnostic instruments was expanded with a multi-representation approach. It is hoped that the use of the three-tier diagnostic instrument in a multi-representational manner can provide a more comprehensive picture of misconceptions that may arise among students. Identifying these misconceptions is a crucial first step in designing Augmented Reality to support students' spatial thinking skills. Thus, this research aims to develop Augmented Reality elements based on an analysis of the results of misconceptions that occur in atomic, molecular, and ionic materials to overcome these misconceptions.

Several previous studies, including the first one carried out by Zarkadis et al (2020) with a research focus on investigating students' basic ideas and misconceptions about the ontological features of atomic identity and behavior, stated that students' age and misconceptions and basic ideas were significantly influenced by the students' own mentality. (Zarkadis et al., 2020). Second, research conducted by Hassan (2023) with a research focus on analyzing the understanding of the concepts of ions and ionic bonds stated that students who received instruction through teaching materials understood the concepts of ions and ionic bonds better than students who received direct instruction. Learning chemistry relies heavily on students' ability to understand microscopic descriptions of how substances are formed and what their functions are (Hassan, 2023).

Based on previous research studies, there has been no research involving the analysis of misconceptions about atomic, molecular, and ionic materials to serve as a basis for developing AR elements. As explained by Peeters et al. (2023), AR applications are able to show virtual models of processes at a submicroscopic level during experiments (Peeters et al., 2023). So the AR development process requires a misconception analysis study in order to obtain AR elements that are right on target in overcoming misconceptions that occur in the field.

METHODS

The research method used in this research is a descriptive method with a qualitative and quantitative approach. Descriptive methods are used to describe misconceptions experienced by students regarding atoms, molecules and ions. A qualitative approach was used to investigate the causes of misconceptions through interviews with teachers. A quantitative approach is used to analyze students' level of understanding of atomic, molecular and ionic material through a three-tier diagnostic instrument. The steps in this research are shown in Figure 1 below.

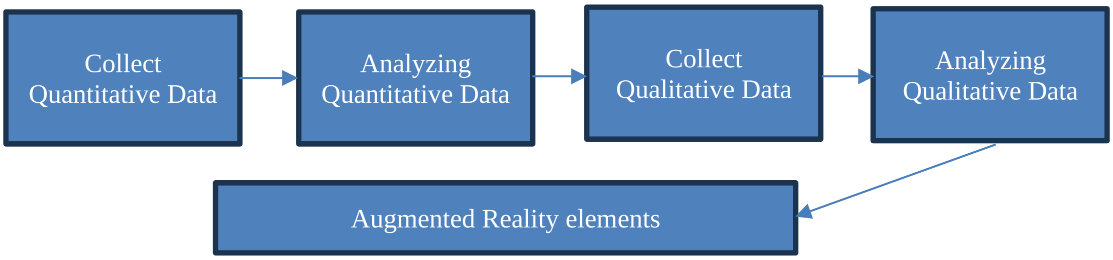

Figure 1. Research steps

The samples used in this research were 2 teachers and 61 students from MA Nahdlatul Falah and Vocational School Karya Budi in Kab. Bandung. The sample was chosen because it met the criteria, including 1) students had studied atoms, molecules, and ions, 2) students had diverse academic abilities, 3) teachers had taught atoms, molecules, and ions, and 4) schools had not too far so that it is easy for researchers to reach and has received permission from the school.

The three-tier instrument developed consists of 15 questions following the interpretation results guidelines, as shown in Table 1.

Table 1. Misconceptions grouping categories

Tier 1	Tier 2	Tier 3	Categories	Code
Right	Right	Certain	Scientific knowledge	SK
Right	Right	Not Certain	Lack of knowledge	LK
Right	False	Certain	False Positif – misconception	M_2
Right	False	Not Certain	Lack of knowledge	LK
False	Right	Certain	False Negatif – Misconception with conceptual understanding	M_3
False	Right	Not Certain	Lack of knowledge	LK
False	False	Certain	Misconception	M_1
False	False	Not Certain	Lack of knowledge	LK

(Sources: Arslan et al., 2012; Mubarak & Yahdi, 2020)

The percentage of students is grouped into categories of understanding the concept, not understanding the concept, and misconceptions, which is calculated using the formula:

$$P = \frac{F}{N} x\ 100\% \qquad (1)$$

P = percentage of students who have misconceptions.

F = number of students who have misconceptions.

N = total number of test participants

The research instrument focuses on identifying misconceptions that may arise in atomic, molecular, and ionic topics by paying attention to questions that represent macroscopic, submicroscopic, and symbolic representations.

To enrich the research data, interviews were conducted with teachers who taught in the class. This information from the teacher strengthens the analysis of misconceptions that occur in students.

RESULT AND DISCUSSION

The three-tier test instrument is designed based on a grid that has been developed, as shown in Table 2 below.

Table 2. Three-tier diagnostic instrument grid for atomic, molecular, and ionic materials.

Topics	Indicator	Item No	Representation
Atom	Analyze the atomic characteristics of an element	1	Makroskopic
		2	Submikroskopic
Molecules: Properties of Molecules	Determine the type of substance based on the chemical formula	3	Symbolic
		4	Symbolic
		5	Symbolic
Elemental molecules and compound molecules	Determine the particles that make up a substance	6	Makroskopic
		7	Symbolic
		8	Symbolic
		9	Submikroskopic
	Analyze elemental molecules and compound molecules based on known information	10	Symbolic
		11	Submikroskopic
		12	Submikroskopic
Molecules and Ions	Analyze the formation of ions from atoms	13	Submikroskopic
	Analyze the differences between atoms and ions	14	Submikroskopic
	Analyze chemical reactions to explain the relationship of ions to molecules and compounds	15	Submikroskopic

The results of the three-tier test instrument analysis can be seen in Table 3 below.

Table 3. Interpretation of three-tier test results

No	Indicator	Representation	Item No	SK	M			M Total	LK
					M_1	M_2	M_3		
1	Analyze the atomic characteristics of an element	Makroskopic	1	27.87%	19.67%	24.59%	6.56%	50.82%	21.31%
		Submikroskopic	2	4.92%	57.38%	11.48%	9.84%	78.69%	16.39%
2	Determine the type of substance based on the chemical formula	Symbolic	3	11.48%	22.95%	34.43%	9.84%	67.21%	21.31%
		Symbolic	4	14.75%	37.70%	11.48%	26.23%	75.41%	9.84%
		Symbolic	5	1.64%	39.34%	11.48%	21.31%	72.13%	26.23%
3		Makroskopic	6	3.28%	27.87%	16.39%	27.87%	72.13%	24.59%

No	Indicator	Representation	Item No	SK	M			M Total	LK
					M_1	M_2	M_3		
	Determine the particles that make up a substance	Symbolic	7	21.31%	14.75%	31.15%	8.20%	54.10%	24.59%
		Symbolic	8	6.56%	27.87%	8.20%	40.98%	77.05%	16.39%
		Submikroskopic	9	3.28%	72.13%	13.11%	3.28%	88.52%	8.20%
4	Analyze elemental molecules and compound molecules based on known information	Symbolic	10	32.79%	13.11%	24.59%	3.28%	40.98%	26.23%
		Submikroskopic	11	6.56%	50.82%	8.20%	9.84%	68.85%	24.59%
		Submikroskopic	12	0.00%	24.59%	9.84%	49.18%	83.61%	16.39%
5	Analyze the formation of ions from atoms	Submikroskopic	13	22.95%	40.98%	1.64%	14.75%	57.38%	19.67%
6	Analyze the differences between atoms and ions	Submikroskopic	14	4.92%	39.34%	4.92%	27.87%	72.13%	22.95%
7	Analyze chemical reactions to explain the relationship of ions to molecules and compounds	Submikroskopic	15	19.67%	18.03%	27.87%	16.39%	62.30%	18.03%
		Mean		12.13%	33.77%	15.96%	18.36%	68.09%	19.78%

Based on the results of field studies, several misconceptions experienced by class X MA and SMK students regarding atoms, molecules and ions have been found. These misconceptions are grouped as M1, M2, and M3. The highest student misconceptions lie in M1, with a value of 33.77%, while M1 and M2 respectively amount to 15.96% and 18.36%, as presented in Figure 1 below.

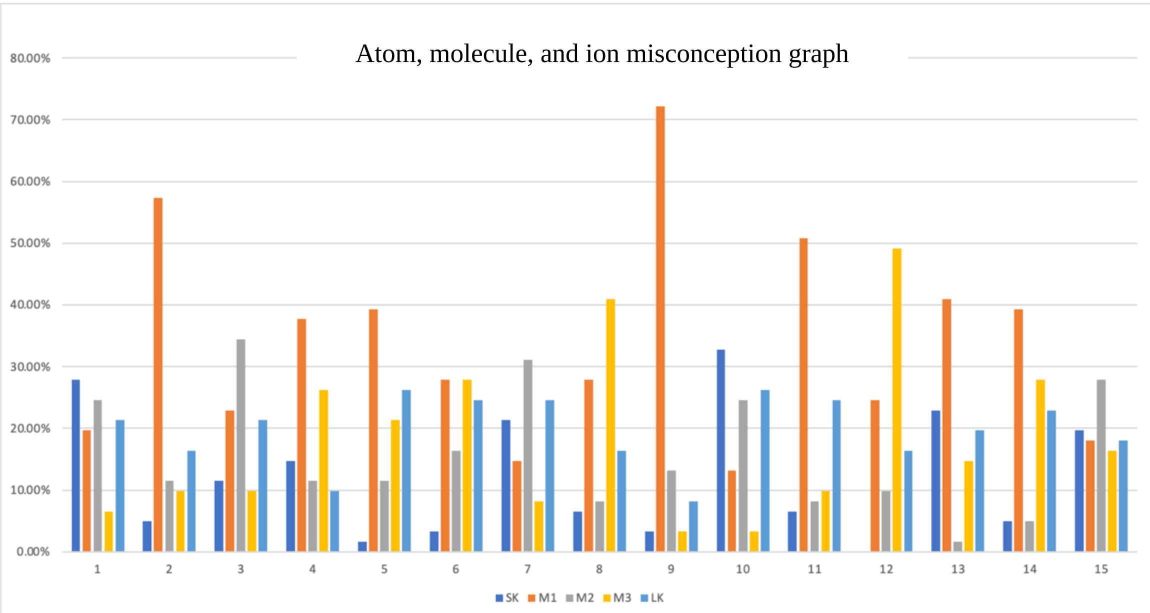

Figure 1. Graph of misconceptions regarding atomic, molecular, and ionic material

M1 misconception is a situation where students answer incorrectly on the first and second tiers but are confident on the third tier. This shows that, on average, students feel confident that the concepts they are learning are correct. The question item in category M1, which has the highest misconception value, is in question no. 9, namely 72.13%, with the indicator determining the particles that makeup substances at the submicroscopic level of representation. This is in accordance with research conducted by Nugrohadi & Chasanah (2022), which states that students, on average, confuse the particles that make up compounds with ionization reactions (Nugrohadi & Chasanah, 2022). Another reason is that students have difficulty projecting phenomena at the submicroscopic level both verbally and visually (Sopandi et al., 2017). Students' lack of understanding of the particles that make up this substance will have an impact on other concepts because this concept is a basic concept that will be used in subsequent chemistry learning materials (Awan et al., 2011).

M2 misconception is a situation where students answer correctly on the first tier but incorrectly on the second tier and are confident on the third tier. This shows that students do not understand a concept but only know the surface, which causes misconceptions. Students who experience M2 misconceptions will find it very difficult to overcome them or even not be able to overcome them at all because false positives are conditions where students answer with full confidence in answers with wrong conceptions even though the answer is correct (Muryani et al., 2022). The question item in the M2 category that has the highest misconception value is in question no. 3, namely 34.43%, with the indicator Determining the type of substance based on the chemical formula at the symbolic level. This is because students do not understand what ionic compounds mean, so they assume ionic compounds are a combination of two different types of elements.

Next is the M3 misconception, which is a situation where students answer incorrectly at the first tier but correctly at the second tier and are confident at the third tier. This shows that students have little information, so M3 misconceptions are not considered a problem because they are caused by students who are careless in choosing answers. The question item in the M3 category that has the highest score is in question no. 12, namely 49.18%, with the indicator analyzing element molecules and compound molecules based on known information at the submicroscopic level. This is because students cannot predict the molecular shape of a compound molecule, but visually, students know that the shape of the molecule consists of more than one type of atom.

The pattern of misconceptions that occur among students based on the results of the misconception analysis above includes the following: first, misconceptions regarding the concept of atoms, namely that students often misunderstand that atoms are solid objects, even though atoms are very small particles and are composed of atomic nuclei and electrons. Then, students often misunderstand that atoms of an element have the same characteristics, even though atoms of an element can have different characteristics, for example, atomic mass, atomic number, and number of electrons. The second misconception about chemical formulas is that students often misunderstand that chemical formulas show the number of atoms of an element in a compound, even though chemical formulas only show the ratio of the number of atoms of an element in a compound. Then, students often misunderstand that chemical formulas show the arrangement of atoms in a compound, even though chemical formulas only show the ratio of the number of atoms of an element in a compound. The third misconception regarding the particles that make up substances is that students often misunderstand that single substances are composed of similar atoms, even though single substances can be composed of similar molecules. Then, students often misunderstand that mixed substances are composed of different atoms and molecules, even though mixed substances can be composed of similar atoms and molecules. The fourth misconception in the concepts of elemental molecules and compound molecules is that students often misunderstand that elemental molecules are composed of the same atoms, even though elemental molecules can be composed of different atoms. Then, students often misunderstand that compound molecules are composed of different atoms, even though compound molecules can be composed of similar atoms. The fifth misconception in the concept of ion formation is that students tend to be mistaken regarding the meaning of a charged atom, such as a positively charged atom, because the atom has an excess of electrons, even though the atom loses electrons because it releases one or several electrons so that the atom has a positive charge.

Overall, the misconceptions that occur include factual misconceptions, conceptual misconceptions, and metacognitive misconceptions. Factual misconceptions are misunderstandings of scientific facts, including (1) color changes can occur due to changes in the composition of the atomic nucleus, which is related to the number of protons. (2) Atoms are neutral because there are protons and electrons. (3) atomic mass is determined by the number of protons; the more protons, the larger the atomic size. (4) Compound molecules consist of three atoms. Conceptual misconceptions are errors in understanding scientific concepts (Suprapto, 2020), including that ionic compounds are a combination of two different types of elements: polyatomic ions consist of two or more positively charged atoms, and polyatomic ions consist of two or more negatively charged atoms. Metacognitive misconceptions are misconceptions related to understanding oneself as a learner, such as students' beliefs about their ability to understand atomic, molecular, and ionic material, including (1) Understanding the concept of atoms, molecules, and ions is easy and (2) Understanding the concept of atoms, molecules, and ions do not need to be memorized. These misconceptions can occur due to internal factors, namely students' difficulties in understanding abstract concepts, limited initial knowledge, and lack of motivation to learn (Ramli et al., 2018). External factors can also be one of the factors causing misconceptions, namely less meaningful learning, less effective use of learning media, and lack of teacher guidance (Pratiwi et al., 2023). Misconceptions experienced by students can hinder their overall understanding of chemistry. This is because misconceptions can cause students to misunderstand basic chemistry concepts. As a result, students will experience difficulty in understanding more complex chemical concepts. Misconceptions can also cause students to develop ineffective learning strategies. For example, students who have misconceptions about atomic structure may memorize chemical formulas without understanding their meaning. This will make it difficult for them to apply these formulas to solve problems.

In addition, interviews are used to obtain further information from the teacher concerned. The teacher interview questionnaire includes (1) What learning methods do you use to teach atoms, molecules, and ions to class X students in general? (2) Do you use concept maps when learning about atoms, molecules, and ions? (3) How do you consider chemical representations (macroscopic, submicroscopic, and symbolic) in explaining atomic, molecular, and ionic material? Based on information from teachers who teach in research subject classes, it can be seen that the inquiry learning method used by the teacher is good enough to encourage students to be active and think critically in studying atomic, molecular, and ionic material. However, there are several things that can be improved to increase learning effectiveness. First, the increasing use of submicroscopic chemical representations. Submicroscopic representations are important to help students understand the concepts of atoms, molecules, and ions in depth. However, in the answers to the interview questionnaire, the teacher only focused on macroscopic and symbolic representations. Second, the application of concept maps which is an effective learning medium to help students understand the relationship between concepts. Using concept maps can help students minimize misconceptions. By applying these two things, it is hoped that learning about atoms, molecules, and ions can be more effective and meaningful for students.

To overcome students' misconceptions, teachers need to improve their representation in learning. Appropriate representation can help students understand chemistry concepts more clearly and easily. Some suggestions to improve teacher representation in overcoming the misconception that atoms are neutral because there are protons and electrons: teachers can use atomic models that show the number of protons, neutrons, and electrons in an atom. To overcome the misconception that atomic mass is determined by the number of protons, teachers can use an atomic model that shows the relationship between atomic mass, number of protons, and number of neutrons. To overcome the misconception that atomic mass is determined by the number of protons, teachers can use an atomic model that shows the relationship between atomic mass, number of protons, and number of neutrons. The model can be in the form of a visual simulation to illustrate the concept in detail.

The visual representations used by teachers in learning atoms, molecules, and ions can be categorized as macroscopic and symbolic representations. Macroscopic representation is shown by images of atoms, molecules, and ions in the form of balls. Symbolic representation is shown by chemical formulas and element symbols. This macroscopic representation can help students understand the concepts of atoms, molecules, and ions in general. However, this representation has several limitations, including not being able to show the actual size and shape of atoms, molecules, and ions and not being able to show the movement of electrons around the atomic nucleus. This symbolic representation can help students understand the relationships between atoms, molecules, and ions. However, this representation also has several limitations, including it can give rise to misconceptions; for example, students think that chemical formulas show the number of atoms of an element in a compound, which can make it difficult for students to understand the concepts of atoms, molecules, and ions in depth. The visual representations used by teachers have not been effective in increasing students' understanding. This can be seen from several misconceptions that occur, as presented in the data analysis chapter above.

Based on the results of the misconception analysis, information was obtained to increase the effectiveness of visual representation through Augmented Reality which is presented in Table 4 below.

Table 4. Required AR elements

No	Misconceptions patterns	AR elements
1	Students have difficulty predicting the molecular shape of a compound	Three-dimensional (3D) models of compound molecules that allow students to interactively manipulate and examine molecular shapes.
2	Students often misunderstand that atoms are solid objects, even though atoms are very small particles and are composed of atomic nuclei and electrons	An interactive animation showing the structure of an atom with its nucleus and rotating electrons, highlighting the nature of very small particles.
3	Students often misunderstand that atoms of an element have the same characteristics, even though atoms of an element can have different characteristics, for example, atomic mass, atomic number, and number of electrons.	An interactive infographic that shows variations in an element's atomic characteristics, such as atomic mass, atomic number, and number of electrons, helps students understand the diversity of elements.
4	Students often misunderstand that chemical formulas show the number of atoms of an element in a compound, even though chemical formulas only show the ratio of the number of atoms of an element in a compound.	Interactive simulation showing how chemical formulas represent the ratio of the number of atoms of an element in a compound, with an emphasis on atomic proportions.

No	Misconceptions patterns	AR elements
5	Students tend to be mistaken regarding the meaning of a charged atom, such as a positively charged atom, because the atom has an excess of electrons, whereas the atom loses electrons because it releases one or several electrons so that the atom has a positive charge.	An interactive model showing the process of losing and gaining electrons by atoms, explaining that the charge of positively charged atoms is caused by losing electrons.
6	Students are confused between the particles that make up a compound and the ionization reaction, even though the writing of the particles that make up the compound and the results of the ionization reaction are different.	A visual animation that differentiates between the particles that make up a compound and the results of the ionization reaction, providing a clear picture of particle changes during the ionization process.

The use of virtual simulation media can visualize the arrangement of particles that make up substances macroscopically (Silaban et al., 2017). In addition, the AR elements developed can provide more detailed explanations to avoid misconceptions.

CONCLUSION

This study identified three types of misconceptions (M1, M2, and M3) experienced by students, with the highest false rate found in M1. These misconceptions include factual, conceptual, and metacognitive understanding of basic chemical concepts. The causes of misconceptions involve internal factors such as difficulties in understanding abstract concepts and limited prior knowledge of students, as well as external factors such as less meaningful learning and ineffective use of learning media. The impact of this misconception is not only limited to a lack of in-depth understanding of atomic, molecular, and ionic material but can also hinder students' ability to understand more complex chemical concepts. Misconceptions can also encourage the development of ineffective learning strategies. To overcome student misconceptions, this research proposes the development of Augmented Reality (AR) based on an analysis of the skills needed to identify misconceptions. AR can help students visualize chemistry concepts in a more interactive and immersive way. The proposed AR elements involve three-dimensional (3D) models of compound molecules, interactive animations of atomic structures, interactive infographics of atomic characteristics, interactive simulations of chemical formulas, interactive models of the process of losing and gaining electrons by atoms, and visual animations of the differences between particles that make up compounds and reactions. ionization. Integrating these AR elements into learning is hoped to increase the effectiveness of visual representations and help students overcome their misconceptions. The use of AR can also provide a more comprehensive learning experience and motivate students to be more active in understanding chemical concepts. Thus, this research contributes to innovative developments in chemistry education through the use of Augmented Reality technology.

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