Available online at
MACCA: Science-Edu Journal (ISSN: 3048-0507)
Journal homepage: https://etdci.org/journal/macca/index

UTILIZATION OF A *FOUR-TIER* DIAGNOSTIC TEST IN UNCOVERING MISCONCEPTIONS ON ATOMIC AND MOLECULAR CONCEPTS

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Received: August 12, 2024 *Accepted: September, 2024* *Online Published: October, 2024*

ABSTRACT

This study aims to analyze the misconceptions experienced by students using a four-tier diagnostic instrument. This study used a qualitative descriptive approach to map the different types of misconceptions on the concept of ions. The main instrument used is a four-tier diagnostic test, which consists of four tiers: the main question (first tier), the student's level of confidence in answering (second tier), the reason for choosing the answer in the first tier (third tier), and the confidence in the answer of the reason (fourth tier). The test questions are presented using multiple representations, including macroscopic, submicroscopic, and symbolic. The results of validation by experts showed that the instrument was valid, with a reliability of 0.6. The study involved junior high school grade IX students who had learned the concepts of atoms, molecules, and ions. The research findings revealed some major misconceptions related to the concept of atoms such as the atomic nucleus is neutral, atoms are the constituent particles of matter that cannot be subdivided, each atom has a certain color, mass number shows the number of electrons, protons, and neutrons, isotopes are atoms with the same mass number, mass number shows the number of electrons, protons, and neutrons, the number of neutrons is equal to the number of electrons, isotopes are elements with different atomic numbers, atomic size depends on the number of electrons. While for the concept of molecules misconceptions that were successfully identified, molecules change shape with phase changes, the temperature of the substance affects the properties of molecules, atoms and molecules are synonymous terms, compounds consist of several types of molecules The results of this study provide deep insight into conceptual errors that need to be addressed to improve student understanding.

Keywords: atoms; molecules; misconceptions; *four-tier* diagnostic test

INTRODUCTION

Misconceptions by some experts are sounded with different terms. Some use the terms *misunderstanding, misinterpretation of facts,* and *naïve belief* (Stojanovska, 2014). There are also those who use the terms *alternative concepts* and *native conception* Luxford & Bretz, 2014). Garnett & Treagust (1992) and Eman (2013) use the terms *alternative frameworks, intuitive beliefs*, and *pre-conceptions.* The number of terms used is due to the fact that the most representative definition has not been obtained in explaining misconceptions. But at least there are some points that become the meeting point of the differences in defining this term, namely that misconception is a natural phenomenon that occurs in almost every student where there are differences in ideas or understanding of students with basic science concepts.

Ideas about science concepts are obtained by students through reading information contained in science textbooks. This information is interpreted differently by each student. Each student will have differences in terms of remembering the same facts and arguments presented in the textbook. This difference is further exacerbated by the fact that many concepts in science are abstract or difficult to understand (Ariandini, 2013; Won, 2014).

In general, misconceptions are defined as the difference between a concept or idea that is built by students' own way of thinking and the ideas of teachers and scientists who work in understanding science concepts (Treagust, 1988; Kaltacki, 2017). In building their understanding of science concepts, students sometimes only think in simple terms while the science concepts to be understood have much more complex characteristics. Misconceptions are also defined as ideas or understandings about a concept that are not based on a basic understanding of science.

Misconceptions are ideas that are not easily eliminated. They are resistant and require serious effort to change (Nicoll, 2010; Suhandi, 2017).

Misconceptions are defined by some as concepts or ideas that differ from current scientific thinking. Any conceptual idea whose meaning deviates from that commonly accepted by scientific consensus. A student's conception that results in a systematic pattern of errors. Student conceptions that are very different from their teachers" or scientists, and resistant to change even in the face of the most determined efforts. They are not errors or wrong answers that result from a lack of knowledge. All definitions of the term misconception agree that students have erroneous ideas or beliefs about scientific concepts and such ideas or beliefs are often deeply held, resistant to change, and inhibit further learning (Fetherstonhaugh & Treagust, 1992; Sanders, 2016).

Misconceptions have several characteristics in common such as the strength of misconceptions embedded in the cognitive structure of students, the concepts owned are different from the concepts of experts. These misconceptions will affect how students understand natural phenomena and provide explanations of these phenomena, and problems regarding misconceptions must be immediately addressed, avoided or eliminated to achieve understanding of concepts that are appropriate or the same as those understood by experts (Hammer, 1996; Samsudin, et al., 2017, p.6).

There are not many studies that specifically examine misconceptions related to atomic molecules and ions. Most research on misconceptions is still dominated by studies on chemical bonding materials. Some articles also specifically discuss only the atomic characteristics of atomic material. From some of the above studies, a list of misconceptions experienced by students in learning the concepts of atoms, molecules, and ions was obtained. Broadly speaking, students' mistake is to assume that the terms atom, molecule and ion are terms with the same meaning whose usage can replace each other. Students are also unable to distinguish between atoms and cells as the smallest unit of a living thing. Furthermore, atoms are considered as a living organism so that when asked to explain the particles that make up inanimate objects such as rocks, students give an explanation that the particles that make up the rock are non-living atoms.

Science concepts such as chemical bonds and atomic particles are very important concepts because they are closely related to other chemical materials or concepts. Failure to understand the concept of chemical bonds will have a great influence on students' ability to understand further chemical materials (Adadan, 2013). The concepts mentioned above are concepts that cannot be observed directly so that students have difficulty in building their mental models.

Errors in understanding chemical concepts are very potential to occur because some phenomena containing chemical concepts are abstract. In addition, the use of difficult language is also one of the obstacles that make chemical concepts even more difficult for students to understand (Ozmen, 2007; Irby, et al., 2016). In fact, it is not uncommon, in learning, science concepts are understood not in accordance with the meaning of the concept itself. This situation as described above is referred to as misconception. One of the few science concepts that are often misunderstood by students is about atoms. The concept of atom is the most basic concept and must be understood by students. Because it is fundamental, failure to understand it will make it more difficult for students to understand further science concepts.

The concept of atom is one of the basic concepts of chemistry that explains the atomic particles consisting of protons, neutrons, and electrons and the influence of these three particles in the formation of molecules. Because the atomic concept is one of the basic concepts of chemistry, it becomes one of the references for other chemical concepts. Most atomic concepts are abstract which often causes misconceptions in students. The misconceptions experienced usually involve errors in understanding the difference between atoms, molecules and ions and the relationship between atomic particles in the formation of molecules (Ozmen, 2004, p.148; Bayrak, 2013). Therefore, students' understanding of the atomic subject matter needs to be known early on. This is done so that the misconceptions experienced by students are known so that solutions can be immediately sought to reduce these misconceptions.

METHODS

The research method used is descriptive qualitative research method by describing the variety of misconceptions experienced by students and the number of students who experience misconceptions. In this study, *a four-tier* diagnostic test was used to identify misconceptions in ionic materials. The source of data was obtained from the results of diagnostic test work by ninth grade students for junior high school. The number of samples used was 80 ninth grade students spread across two junior high schools in Bone Regency.

The research implementation procedure was carried out by giving students a *four-tier* diagnostic test instrument to work on. This instrument consists of eight items with four levels ranging from the choice of student answers, the level of confidence in choosing answers, the choice of student reasons, and the level of confidence in choosing reasons. From the results of the work, students' answers will be inventoried to find out what types of misconceptions students experience in ion material. From the results of student answers, they will be grouped into five levels of *conception,* including *scientific conception, misconception, false positive, fals negative,* and *lack of knowledge*. Incomplete student answers because they do not provide answers to the *four* levels of questions on the *four-tier* diagnostic test will be classified as error answers so they are not included in the existing conception levels. Determination of students' conception level can be determined if students answer completely all four levels of questions on each item.

RESULTS AND DISCUSSION

RESULTS

For each item, there are three types of misconceptions that can be identified with this diagnostic test instrument. The three types of misconceptions are found in the third *tier*. The decision on the type of misconception experienced by students for each item is determined from the answer options chosen by students in the third *tier*. After the questions were given, students were asked to answer each tier of the questions. The construction of each item contained misconceptions on the concept of atoms and molecules.

A total of 24 items representing several misconceptions spread across three concepts, namely atoms molecules and ions, were identified. The misconceptions for each item are in the 3 choices of reasons in the third *tier*. The reasons in the third *tier* are the result of a combination of several students' alternative concepts (identified misconceptions) obtained from the *open-ended test* instrument given by students and the results of the literature review. Broadly speaking, the misconception targets identified can be seen in Table 4.6. The misconception targets shown in Table 4.6 are still general. More specific and detailed misconceptions for each item will be explained in Table 4.7. The order of explanation will begin with the concept of atoms. The question items representing the atomic concept consist of 9 questions, namely numbers 1, 2, 3, 4, 5, 8, 12, 24, and 23. Meanwhile, the molecular concept consists of 7 numbers, namely 7, 9, 10, 11, 16, 18, and 20.

Table 1. Target Misconceptions

No.	Concept	Target Misconception
1	Atom	1. The size of an atom depends on the number of protons it has
		2. Each atom has a specific color
		3. Atomic nuclei are neutral
2	Molecules	1. Molecules deform with phase change
		2. The temperature of the substance affects the molecular properties

3.	Atom and molecule are synonymous terms
4.	Compounds are made up of several types of molecules

DISCUSSION

1. Misconceptions on the Atomic Concept

As previously described, there are three indicators of items on the atomic concept represented by items number 1, 2, 3, 4, 5, 8, 13, 15, 20, 27, 28, and 29. Because there are several items that represent the same indicator, the discussion of misconceptions on items with the same indicator will be discussed simultaneously. Also to avoid repetitive discussion. Likewise, with other indicators on the concept of molecules and ions

a. Determining Atomic Particles (Problem Numbers 1, 2, 3, 12, and 24)

In the atomic concept for the indicator of determining the constituent particles of an atom, the percentage for misconceptions is 38.15%. The form of misconception is that the number at the top of the notation shows the mass number which is the number of protons and electrons. Students' reasoning choices that identified student misconceptions were found in the reasoning choices of part C of item number 3. Students assume that the mass number shows the number of electrons and protons. The mass number should be a measure of the weight of an atom determined by the number of protons and neutrons. This error may be due to the fact that students assume that the most important particle in the atom is the electron, thus ignoring other particles. In addition, it may be due to the frequency of electron particles explained in class by the teacher more often than other particles, namely protons and neutrons.

In question 2, there were also misconceptions similar to this. Some answers given by students assume that the mass number is the sum of the three atomic particles, namely protons, neutrons and electrons. If analyzed at a glance, this assumption is very likely to appear in students' concepts because the definition of mass is the total of all the constituent particles. Students do not understand that only protons and neutrons contribute to the mass of an atom. The electrons are not included in the calculation of atomic mass because the mass of an electron is so small that it can be ignored (Chang, 2004: 36).

Another form of misconception is that the number at the bottom of the notation indicates the number of neutrons. Students are not clear in distinguishing between the constituent particles of an atom. Especially for neutron particles, because in the notation of chemical elements the number does not appear in the notation so that the number is always equated with electrons. The author suspects that this misconception is caused by students' low understanding of the symbolic level. Another cause is because students learn a concept by memorizing so that the learned concept is not strong. Students do not understand the role of the existence of atomic constituent particles to the existence of an atom.

Another misconception in this indicator is the student's assumption that the neutral is the nucleus of the atom while the correct concept is that the neutral is the atom as a whole not the nucleus. The nucleus of the atom is positively charged. This charge is determined by the positively charged protons. Atomic neutrality is caused because the number of protons and electrons is the same. The cause of this misconception, according to the author's assumption, is that students misinterpret the teacher's explanation of neutral atoms. In addition, in the answer choices, another reason identified for misconceptions is because atoms are neutral so that what surrounds the atomic nucleus must be positively and negatively charged particles, namely electrons and protons.

In item number 12, there are also misconceptions experienced by students. Students assume that the atom is the smallest material that cannot be divided again. While the atom itself has three constituent particles, namely protons, electrons, and neutrons. This misconception is thought to be caused by students not receiving material about atomic theory thoroughly. Students only get to the atomic theory according to Dalton. It could also be caused by the teacher's inaccurate explanation in providing analogies in explaining atomic concepts. The author has implemented an analogy model with a piece of paper that is torn continuously so that in the end a part of the paper is obtained

that cannot be divided anymore and it is concluded that that is what is meant by an atom. This analogy can be used to open students' initial insights about atoms as a term that they just got.

b. Explaining the Atomic Characteristics of an Element (Problem Numbers 5, 8, and 23)

The misconception in this indicator is that students assume that each atom has a certain color. Students' answers that identified misconceptions were that gold atoms are gold in color. Whereas in identifying an atom, color is not the right indicator. Atomic color cannot be used to identify the characteristics of an atom because atoms in a single state do not have properties such as color, shape, and density. These properties can be known if similar atoms combine to form a collection of atoms in certain ways. The characteristic of an element is indicated by the atomic number of the element. This misconception may be due to students' associative thinking. Students associate gold atoms with gold-colored objects such as gold rings or bracelets that they have seen before.

In item number 23, misconceptions were identified regarding the characteristics of an atom that an atom has an uncertain shape so that it can change. Students assume that the atoms in the cans that are crushed because they are run over by car tires experience a change in shape from their initial state which causes the atoms in the cans to also become crushed. Another assumption that indicates misconception is that pressure causes atoms to crumble. In fact, no matter how much pressure is applied to an object containing certain types of atoms, it will not change the shape of the atoms. This misconception stems from students' experience that the structure of an object will change if the object also changes shape. This kind of error can stem from students' erroneous reasoning process and can also be caused by experiences gained by students in their daily lives regarding the change in shape.

c. Explaining the Definition of Isotope (Problem Item Number 4)

In general, the misconception in this item is that isotopes are found in elements with different atomic numbers. Students assume that the different functions of isotopes described in the question item indicate that the two isotopes are two elements with different atomic numbers. There are also some student answers that lead to the misconception that isotopes are atoms with the same mass number. This assumption appears in students' conceptions perhaps because they think that when the atomic number is the same then all other variables in the atom are also the same including the mass number. The cause of these two misconceptions may be due to students' low ability or it may also be due to the wrong reasoning process.

2. Misconceptions on the Concept of Molecules

Misconceptions on the concept of molecules are divided into three parts according to the indicators of the item grid. Each indicator is represented by several items. Similar to the atomic concept above, misconceptions on molecular concepts will also be discussed per indicator. To avoid repetitive discussion, the items representing the same indicator will be discussed simultaneously.

a. Explaining the Effect of Temperature on the Shape and Size of Molecules (Question Numbers 7 and 9)

The misconceptions found in these two questions are the same. The focal point of the misconception is that there is a student misunderstanding about the effect of temperature on the shape and size of molecules. Students assume that temperature affects the shape and size of molecules so that in question number 7 there are 11 (39.29%) students answered in the reason option that when iron metal turns into iron melt because it is heated, the shape and size of molecules change. Whereas according to the existing theory, the difference between iron metal and iron melt is due to changes in the arrangement or distance between molecules due to heating. The molecules in iron metal are tighter than the molecules in iron melt. The reason answer option that also contains misconceptions and is chosen by students as a reason is that molecules change shape with phase changes. The change in the form of iron metal to iron melt does not cause a change in the shape and size of the molecules. The only change is that the distance between molecules in iron metal is tighter than in iron melt. The difference in the form of water into ice is not caused by temperature and the changes also do not change the shape and size of the molecules. The change only occurs in

the distance between H_2 O molecules in ice is tighter than in water. According to the author's assumption, this misconception may be caused by students misunderstanding the teacher's explanation and also students are weak in representation skills at the submicroscopic level.

b. Differentiating Element Molecules and Compound Molecules (Question Numbers 10, 11, 16, 18)

These four items have the same target, namely to identify misconceptions experienced by students on the concept of molecules, especially in distinguishing between element molecules and compound molecules. In item number 10, there are several students who choose *option* C. Students assume that nitrogen gas and oxygen gas are compound molecules because both are composed of more than one atom. This assumption is classified as a misconception category because compound molecules are formed when two or more non-similar atoms join. If the molecule is only composed of similar atoms then the molecule is called an elemental type of molecule. The cause of this misconception could be because students make a *fallacy* (error) in thinking by overgeneralizing about the meaning of molecules. Students may assume that the term molecule in all cases has the same definition, namely the joining of two or more atoms. This is also the case in question numbers 16 and 18.

In question number 11, there are still students who give a combination of answers that identify misconceptions. In the answer choices for the main question, 5 students answered that I_2 is an ion and chose the reason that I_2 is formed from the combination of I^- ions. Students assume that the formation of a molecule involves the combination of ions after passing through the electron transfer process. Pairs or combinations of ions do not form molecules but rather form compounds. Molecules are formed from the combination of elemental atoms of both atoms of the same element and different elements. This misconception may be due to students misinterpreting the concepts received from the teacher's explanation or what they learn in the textbook.

c. **Determining the Particles (Atoms and Molecules) of a Substance (Problem Number 20).**

This item identified the misconception that mercury is a form of molecule. From some of the answers given by students, there were 5 students who answered that mercury is a molecule. The reason given by students who answered that mercury is a molecule was that mercury is a combination of different elements. The author assumes that the students chose this reason because the main question contained the phrase mercury. The phrase mercury caused the students to assume that mercury is a combination of water molecules and mercury metal. A total of 14 students answered that mercury is a compound on the grounds that mercury contains a small amount of water. In fact, mercury is a metal element so its constituent particles are free atoms. The most likely cause of this misconception is because students are wrong in reasoning about the main question in the problem.

CONCLUSION

Atomic nuclei are neutral, atoms are particles of matter that cannot be divided again, each atom has a certain color, mass number shows the number of electrons, protons, and neutrons, isotopes are atoms with the same mass number, mass number shows the number of electrons, protons, and neutrons, the number of neutrons is equal to the number of electrons, isotopes are elements with different atomic numbers, atomic size depends on the number of electrons.

As for the concept of molecules, the misconceptions that were identified were that molecules change shape with phase changes, temperature affects the properties of molecules, atoms and molecules are synonymous terms, compounds consist of several types of molecules.

Research on misconceptions is still very much experienced by students, especially for concepts that cannot be observed directly, so it requires a learning approach and the use of learning media that can accommodate these limitations. Therefore, future researchers are very useful if they are able to maximize the plural representation approach and a more accurate identification model.

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