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Science Students' Misconceptions of Basic Concepts of Chemistry on Matter and Its Particulate Properties

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Abstract
This paper aims to explore and discuss students' misconceptions in explaining and representing matter and its particulate nature. The study was conducted quantitatively where data were obtained and analyzed through a two-level diagnostic test. Students' misconceptions are assessed based on objective answers in the first level. Then, in the second level, misconceptions are assessed based on open-ended questions that require students to construct a written descriptions as well as particle diagrams. Sixty secondary school students (age fourteen) participated in this study. Wilcoxon sign rank test analysis revealed that the median of the null hypothesis compared to each item median in diagnostic test have a significant difference of the diagnostic test at the significant level of 0.05. Based on the results, it turns out that each students have misconceptions on 100% of the items. Those misconception about basic chemical concepts are comprising both at the macroscopic and microscopic levels. Such misconceptions make it difficult for students to determine the exact facts and build explanations including representing particles that are coherent with the scientific facts between the observed phenomena and the phenomenon of particles. As a result, students face challenges in order to build conceptual understanding on the topic about matter and its particulate nature. The results of the study also enable appropriate learning methods to be developed specifically to overcome the misconceptions of basic chemical concepts in middle school.
Keywords: Basic Concepts of Chemistry, Matter, Particles, Macroscopic and Microscopic Levels, Misconceptions, Conceptual Understanding

Introduction and Background

Mastery of basic chemical concepts is important to build at an early stage of education (Allen, 2019; Nuić & Glažar, 2019; Okumuş & Doymuş, 2021). This is to enable students to have a solid foundation in the concept of chemistry (Elmas et al., 2020; Laliyo et al., 2020; Su, 2020). Furthermore, it can help students to learn chemistry that involve more complex concepts (Supasorn, 2015). In Malaysia, students in middle school are being expose to chemical concepts in science topic namely Matter that will be learn in Form 1. Learning standard requires students to understand about matter in nature, the concept of physical states and changes state of matter as well as its particles properties. This basic concept was found to involve macroscopic and microscopic levels of chemical knowledge. However, students tend to have misconceptions about this topic (Martinez et al., 2021; Okumuş & Doymuş, 2021). This situation causes students to be unable to determine the exact facts (Kirbulut & Geban, 2014; Lu & Bi, 2016; Saat et al., 2016), unable to elaborate a description of the phenomenon observed (Colclasure et al., 2020) and represent the particle phenomena that are in line with scientific concepts (Gkitzia et al., 2020; Martinez et al., 2021; Moon et al., 2019; Pavlin et al., 2019; Zarkadis et al., 2021).

Common misconceptions in basic chemistry topics have been reported in many previous studies. For example, students tend to give macroscopic characteristic to particles (Cole et al., 2020; Nuić, 2018; Zarkadis et al., 2021). Where, particles are assumed to freeze during the cooling process, expand or contract as happens to matter, liquid particles are larger in size than solid particles'(Yaseen, 2018), solid matter in a fine-grained state is considered as fine particles'. Students are also confused between matter and non-matter. For example, heat is considered like matter i.e. in a gaseous state where it is made up of fine particles. In addition, students are shown to represent particle diagrams that are not in line with the scientific facts studied (Klutse, 2021; Ryoo et al., 2018b; Slapničar et al., 2020). These findings reveal that students have difficulty understanding concepts at both the macroscopic and microscopic levels. Furthermore, students find it difficult to establish a relationship between the state of matter and the phenomena that occur at the particle level. It is important that misconceptions are detected so that learning is processed to guide students to improve the knowledge they have built in accordance with scientific facts (McLure et al., 2022; Saat et al., 2016; Supasorn, 2015; Üce & Ceyhan, 2019).

Methodology

In order to achieve the objective which to identify students' misconception of a basic concept in chemistry in targeted topic, a thorough analysis had been done to identify the cause of the problems of learning chemistry concepts based on previous studies. Research done is focusing on introductory chemistry topics that might be learnt at primary to higher level of education involve basic concepts of chemistry. Subsequently, the researcher further formed the research objectives to solve the learning problems studied.

Taber had asked "is it enough if the student has answered the test questions correctly, then the student has been counted as learning?" (Taber, 2019c). Through this, testing students understanding of the concept should not only emphasize students' achievement without assessing the conceptual understanding of the content. It should be emphasized the need to determine students' conceptual understanding so that chemistry learning is meaningful (De Andrade et al., 2019; Heeg et al., 2020; Lu & Bi, 2016). That is, where the learning objectives are achieved and the knowledge built by students covers the levels of chemical knowledge (Cole et al., 2020; Cooper & Stowe, 2018; Lansangan et al., 2018; Rodriguez et al., 2018; Stowe et al., 2021).

To enable students to express their conceptual understanding, the instrument use to recognize misconceptions in students' existing concepts is in the form of a two-tier diagnostic test. The first tier of the items is multiple choice objective question purposely to detect misconceptions on students' content knowledge (Lu & Bi, 2016; Saat et al., 2016; Supasorn & Amatatongchai, 2016). This level requires students to choose accurate scientific facts either about macroscopic phenomenon or statements about microscopic phenomena based on the situation given. Most multiple answer statements were build based on the misconceptions of students reported from the findings of previous studies while meeting the learning standards. On the second tier, students are required to construct a written description along with a drawing of a particle diagram to represent the description of their answer. Some of the questions are provided with a discrepant event related to the concept. This has been done so that students will not only rely on their memory but to test their conceptual understanding.

1.1 Figure 1.1 shows two balloons filled with air tied to a balance sheet.

Figure 1.1

Which of the following is the correct explanation of Figure 1.1?

a. Gas particles have mass and can be observed under a microscope.
b. The gas particles have mass yet cannot be observed under a microscope.
c. Air although it cannot be observed with the naked eye, it has mass and its' particles can be observed using a microscope.
d. Others :____

1.2 Figure 1.2 shows two balloons containing different gases both with the same volume. Balloon A contains gas A, while balloon B contains gas B. These balloons are tied to a weight.

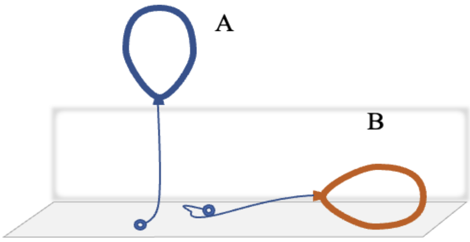
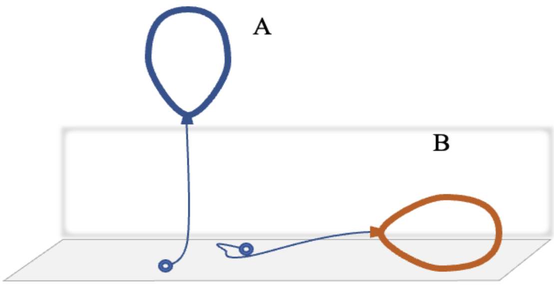


Figure 1.2

Draw the gas particles inside balloon A and B. Explain based on your observations and relate the conditions (such as position, arrangement, size) of the gas particles.



Description : ____
____
____

Figure 1 Example of two-tier diagnostic test item

The following are the rubric that had been used as indicators to determine whether a student's knowledge held any misconceptions or has reached conceptual understanding. This level of understanding is arranged from the lowest level of no understanding to the highest level of conceptual understanding. Through Taber (2018a), the concepts held by the students are inadequately assessed from a macroscopic perspective or the students description of the physical state of matter only. Meanwhile De Andrade et al. (2019) underlined, students' explanations of chemical phenomena must be relevant to the context and use appropriate chemical representations, including giving descriptions from microscopic level, which represent the process that occurs behind the phenomena observed by the naked eye. Though, this rubric is built so that students' knowledge can be assessed at both macroscopic and microscopic levels knowledge.

Table 1
Rubric for Analysing Students' Answers in Diagnostic Test

Level	*Definition of analysis*
0	No answer No multiple-choice answers, no drawings or written explanations
1	Answers contrary to scientific facts/ Misconceptions Wrong multiple-choice answer
2	Part of the answer is in line with scientific facts. Part of the answer is incorrect or contrary to scientific facts/ Misconceptions
3	The answers are in line to scientific facts but incomplete.
4	All answers are in line with scientific facts. Drawings and explanations are relevant

The data from these diagnostic tests are then analyzed using a rubric and transferred to SPSS software.

Result and Discussion

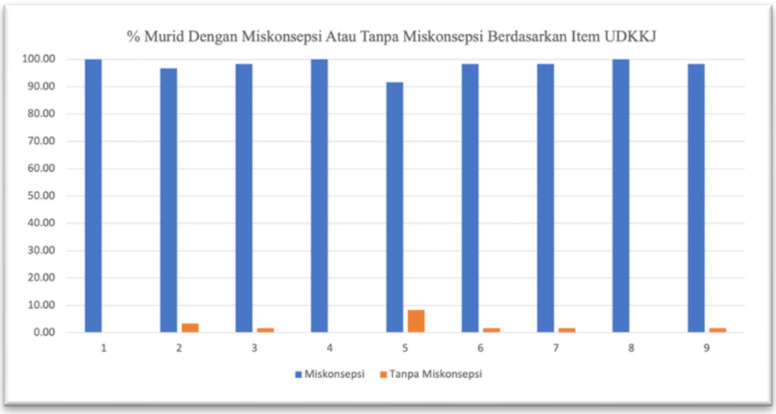


Figure 5 Graph of Misconception Frequency Based on Diagnostic Test Items

Based on Figure 5, the graph is gained from the descriptive analysis for a brief insight of the research. The frequency shows that 90 -100% of students have misconceptions of each diagnostic test item. The data analysis was carried out using a non-parametric statistical test (*One-Sample Wilcoxon Signed Rank Test*).

Table 2

Result of Wilcoxon Signed Rank Test Against 9 Items in Diagnostic Test

Item	Sig Value	Median	
		Null Hypothesis	Study Findings
1	<.001	3	2
2	<.001	3	2
3	<.001	3	2
4	<.001	3	1
5	<.001	3	2
6	<.001	3	1
7	<.001	3	1
8	<.001	3	2
9	<.001	3	1

The median for null hypotheses is set to 3 indicates no misconceptions while the values of 1 and 2 indicates misconceptions with a significant level of .05. Statistical analysis of each item shows that the value (sig <.001) of each item is less than .05. This statistical test showed that there was a significant difference between the null hypothesis value and the findings of the study. With this, the null hypothesis that there is no misconception is rejected. The data shows that students' conceptual understanding still demonstrate various misconceptions on matter and its particles properties.

The following are some of the evident of students' misconceptions about the basic concept of chemistry in the topic of matter. For each of the following items, the particle diagram produced by a student refers to the knowledge at the microscopic level. The students had to draw a particle diagram that corresponded to the state of the gas inside the two balloons. Misconceptions about particle properties in students' existing knowledge are found to be expressed when exposed to two different situations involving the same physical state of matter. For example, how a student represents the effect of two different gases on the buoyancy of a balloon.

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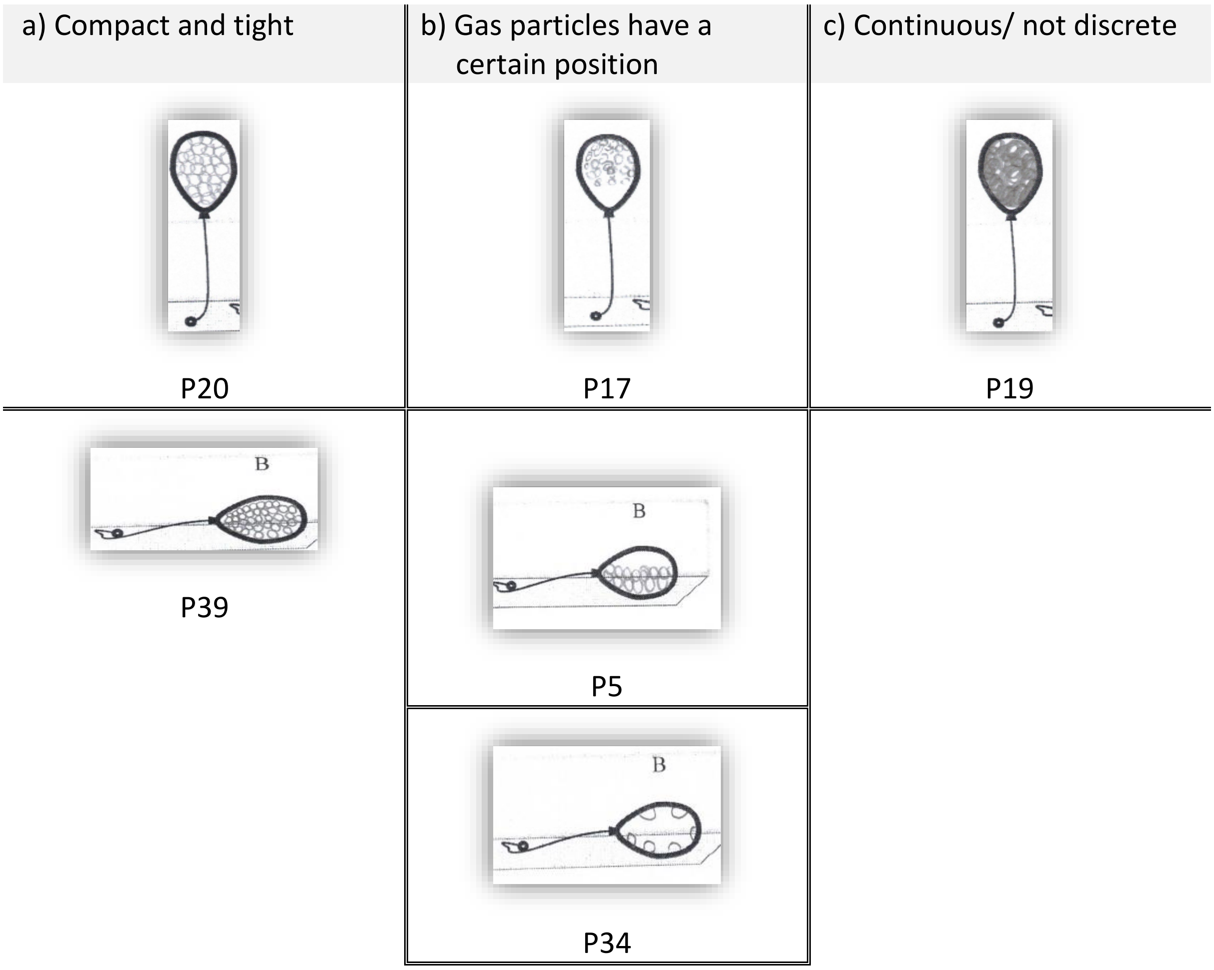


Figure 2 Misconception in particle arrangement for gases regarding their effect on a balloon's buoyancy

As shown in column (a) the misconception in particle arrangement for gases is described as tightly arranged like solid particles. Based on the student's (P20) written explanation, the diagram was produced due to the large and dense amount of gas in balloon A that make it floats. While another student (P39) depicts the same arrangement of particles in balloon B, but with different interpretation. He or she assumed the balloon can't float due to large and dense number of particles. As in column (b), the gas particles are depicted as occupy a certain position like 'above'; 'below'; 'at the edge only-with an empty space in the middle of the balloon'. Students seem to have a confusion towards the properties of particles and the characteristic of matter. Students did represent that particles floats like the gas rather than particles occupy space of the balloon which let both balloons to inflate. Meanwhile, for column (c), the particle diagram is shown to have a continuous structure as opposed to the properties of particles that are discrete. This misconception had been reported through a study by Mamombe et al. (2020). He classified misconception that shown in column (b) and column (c) as animistic model and continuous animistic model. This is because students believed that air behaves like animals.

Based on these findings also, students tend to apply macroscopic characteristics on particles. This was shown by students when they are required to represent solids in two different sizes which are in a form of large lumps (rocks) and granules (sand).

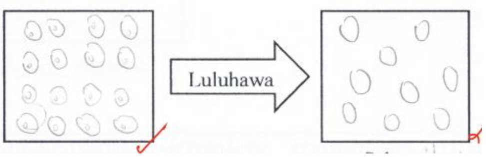
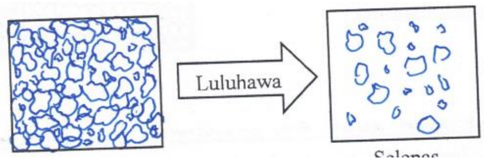
a) The particles for sand are shown to be far apart like the arrangement of particles for gases.	b) Particles of rocks have the appearance of rocks rather than spherical.
 P6	 P30

Figure 3 Representing particles with macroscopic characteristic

Through column (a), student P6 able to draw rocks' particles arrangement correctly but for sand, the particles arrangement is incorrect. As sand appear smaller than rock, students represent sand particles as the same as the properties of gas particles. In column (b), students represent the shape of particles as it has the same shape of rocks and sand. Besides, in this form of misconception, students not only showing it through their visualization but also through their written explanation. As in this figure below, student visualized particles in alternative concept as identified from the written explanation. This student had misinterpreted dew or water droplets as the particles of matter. Students are figured to believe that tiny objects such as sand, dew or water droplets are the particles of matter rather than as matter. According to Allen (2019), why students tend to claim such explanation is because it requires students to think in abstract way in order to make sense what is happening to a material at the microscopic level. By the evident in Figure 3 and Figure 4, it can be determined that either in drawing or in written explanation student might apply such misconceptions.

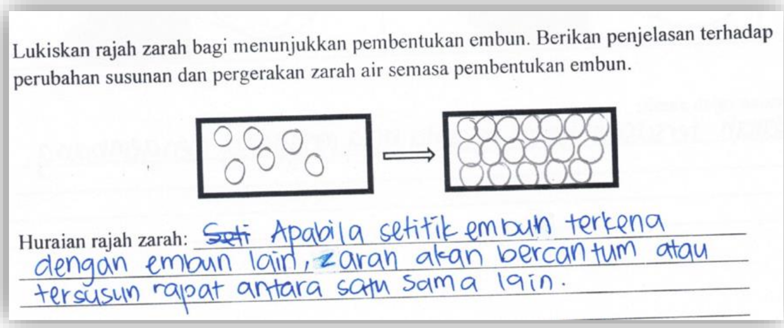


Figure 4 Spheres of particles are depicted as dew or water droplets

Conclusion

Based on the findings of this study, it is evident that students still have misconceptions about the basic concepts of chemistry in the topic of matter. The study also revealed that students are unable to interpret observable phenomena on matter using precise scientific facts. In addition, students are also unable to represent the phenomenon of particles that occur on matter according to the concepts involved. This may be the case because students tend to use intuition rather than scientific facts. Meanwhile, for students who have knowledge of scientific facts, they are struggling in applying existing knowledge when they fail to connect written descriptions with representations of particle diagrams. This misconception of macroscopic and microscopic phenomena shows that the knowledge of students at these two levels is hard to connect. Therefore, students need to be empowered with learning activities that can connect the two levels of knowledge. The findings of the present study suggest that learning should incorporate both inquiry and visualization method in eliciting improvement in conceptual understanding and reducing misconceptions regarding matter and its particulate phenomena.

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