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An analysis of gender difference on students' misconceptions in learning the material classification and its changes

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Abstract

Every teacher has experiences to identify and find out students who have misconceptions in their classrooms. Misconceptions that occur can differ between male and female students. The purpose of this study was to analyze the effect of gender on misconceptions in the lesson of the material classification and its changes. The survey-aiming method was used in this study. A total of 62 students from one of the state junior high schools in the city of Surakarta consisting of 34 male students and 28 female students were involved as the subjects in this study. Identification of misconceptions was conducted using the Two-tier multiple-choice diagnostic instrument that was equipped with the Certainty of Response Index method. The formulation of this study problem was: "How are the differences of misconceptions between male and female students in learning the material classification and its changes?" This study showed that female students tended to have misconceptions on the competency achievement indicator *vis-a-vis* explaining the understanding of elements, compounds and mixtures, while male students tended to have misconceptions on the competency achievement indicator pertinent to distinguishing elements, compounds, and mixtures. In general, female students had better conceptual knowledge than male students. The two-tier multiple-choice instrument could be used as an alternative instrument to identify misconceptions among students. The results of this study are expected to be a reference for educators to identify and resolve students' misconceptions.

Keywords: gender difference, misconceptions, two-tier multiple choice, certainty of response index, material classification and its changes

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INTRODUCTION

Research has shown that students enter science classes by bringing many pre-formed ideas. These ideas often lead students to make predictions and build explanations that are different from those derived from scientific theories and practices that are currently accepted (Stains & Talanquer, 2007). Different concepts from the generally agreed scientific understanding of a term are called misconceptions (Modell, Michael, & Wenderoth, 2005; Taber, 2009; Yamtinah, Indriyanti, Saputro, Mulyani, Ulfa, Mahardiani, Satriana, & Shidiq, 2019).

Misconceptions or misunderstandings as such have been widely defined by researchers. They even use various terms to define misunderstandings that occur to students such as the use of the terms *alternative conceptions* (Adadan & Savasci, 2012; Atasoy, Akkus, & Kadayifci, 2009; Hsu, Tsai, & Liang, 2011; S. W. Lin, 2004; Tan, Taber, Goh, & Chia, 2005), *naïve conceptions* (Babai & Amsterdamer, 2008; Reiner, Slotta, Chi, & Resnick, 2000; Walker, 2012), *intuitive Conceptions* (Lemmer, 2013; Marzabal, Delgado, Moreira, Barrientos, & Moreno, 2018), *prescientific conceptions* (Sen & Einstein, 1973), and *students' intuitive theory* (Heintz, 2012; Lickel, Rutchick, Hamilton, & Sherman, 2006; Marzabal, Delgado, Moreira, Barrientos, & Moreno, 2018; Soll, 1999).

Every teacher has experiences to identify and find students who have misconceptions in their classrooms (Modell, Michael, & Wenderoth, 2005). When students connect new information or concepts to cognitive structures that already have misconceptions, this interferes with further learning. Thus, weak understanding or misunderstanding of concepts will occur because new information cannot be linked precisely to their cognitive structures (Nakhleh, 1992; Satriana, Yamtinah, Ashadi, & Indriyanti, 2018). Therefore, identification of students' conceptual knowledge in science classes is an important thing to do.

Study results state that identification of students' conceptions can be done in various ways, such as conducting in-depth interviews with students (Osborne & Gilbert, 1980), using concept maps (Novak, 1995), and deploying multiple choice diagnostic tests (D. F. Treagust, 1988). In addition, identification of students' conceptions has been carried out on various topics about science, such as chemical bonds (Boo, 1998), heat and temperature (Ratnasari, Sukarmin, Suparmi, & Aminah, 2017), molecules and atoms (Griffiths & Preston, 1992; Nakiboglu, 2003), circular motion (Kaiser, Mccloskey, & Proffitt, 1986), and phase changes of a substance (Bar & Travis, 1991). In this study, the focus is on identifying students' conceptions using a two-tier multiple-choice diagnostic instrument on the topic of the material classification and its changes.

This topic was chosen based on the preliminary study conducted in one of the junior high schools in Surakarta, and it was known that students still had difficulties in the indicators *vis-a-vis* distinguishing changes in physics/chemistry, determining the separation of mixtures, determining the solution of acids, bases and salts, and determining atoms, ions or molecules. Therefore, it is necessary to detect the mastery of concepts and to identify misconceptions. The use of the Two-tier Multiple-Choice instrument to identify students' conceptions has been widely carried out. It is such as in the identification of conceptual understanding of chemistry in high school students (Osman & Sukor, 2013), in the research on students' misconceptions in biology (Fisher & Moody, 2002), in the investigation of the relationship between students' conceptions of the nature of matter and their understanding of chemical bonds (Othman, Treagust, & Chandrasegaran, 2008) and in identification of students' conceptual understanding in various fields (Atasoy, Akkus, & Kadayifci, 2009; Aydin-Gunbatar, Tarkin-Celikkiran, Kutucu, & Ekiz-Kiran, 2018; Chandrasegaran, Treagust, & Mocerino, 2007; Lin, 2004; Tan, Taber, Goh, & Chia, 2005).

Combining the Certainty of Response Index (CRI) method with a two-tier instrument is an attempt made in this study to increase the research novelty and make it easier to analyze students' conceptions. CRI is a misconception detection method, wherein students must show their confidence in the answers they have chosen (Hasan, Bagayoko, & Kelley, 1999). The confidence scale used in this CRI is 0-5. The advantages of this method are in terms of ease, accuracy, and speed of the process to identify and analyze data (Diani, Alfin, Anggraeni, Mustari, & Fujiani, 2019; Helmi, Rustaman, Tapilow, & Hidayat, 2019).

Both male and female students qualitatively have different abilities in the field of science (Yamtinah, Masykuri, Ashadi, & Shidiq, 2017). Literature of gender differences in science education has distinguished between female and male students about their interests, attitudes, and motivations towards science (Britner, 2008; Mattern & Schau, 2002; Shemesh, 1990). This study aims to investigate gender differences in terms of students' misconceptions on the topic of the material classification and its changes using a two-tier multiple-choice instrument equipped with CRI. This study is expected to add a novelty to the method in identifying students' conceptions and can be used as a reference for teachers and researchers to conduct further studies.

METHOD

The survey-aiming method was used in this study. A total of 62 students from one of the state junior high schools in the city of Surakarta consisting of 34 male students and 28 female students were used as the subjects in this study. Identification of misconceptions was carried out using the Two-tier multiple-choice diagnostic instrument that was equipped with the CRI method. The items used amounted to 30 items. The example of the instrument used is shown in Table 1. CRI criteria are displayed in Table 2. Guidelines for classifying students' conceptions are shown in Table 3. The problem formulation used in this study is; how are the differences of misconceptions between male and female students in learning the material classification and its changes.

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Table 1. *The Example of Two-tier Multiple-Choice Instrument*

Competency Indicator	Distinguishing elements, compounds, and mixtures
The Indicator of question	Students can analyze the application of mixed forms correctly
Question	Soda water has the chemical formula H_2CO_3. To make soda water, the most important component is water and carbon dioxide gas. Soda water is made by dissolving carbon dioxide (CO_2) gas into water. When injected into water with high pressure, carbon dioxide will form carbonic acid. That is why this drink is called carbonated beverages. Carbonic acid is what causes the distinctive touch of soda in the mouth and the feeling of biting when drunk. In that context soda water can be classified as ... A. Mixture B. Molecule C. Compounds D. Atom Reason A. Because there is a mixture of water and carbon dioxide compounds B. Because soda water contains carbon dioxide compounds C. Because soda water is a heterogeneous mixture

Scale	CRI Criteria
0	*Totally guessed answer*
1	*Almost guess*
2	*Not Sure*
3	*Sure*
4	*Almost certain*
5	*Certain*

Table 2. *CRI Criteria*

CRI Scale	Criteria	Information
0	*Totally guessed answer*	If in answering the question the answer is100% guessed
1	*Almost guess*	If in answering the question the percentage of guessing is between 75% -99%
2	*Not Sure*	If in answering the question the percentage of guessing is between 50% -74%
3	*Sure*	If in answering the question the percentage of guessing is between 25% -49%
4	*Almost certain*	If in answering the question the percentage of guessing is between 1% -24%
5	*Certain*	If in answering the question there is no guessing at all (0%)

Table 3. *The Criteria for the Concept Understanding*

No.	The answer	Reason	CRI	Categories
1.	Right	Right	High	Understanding the Concept
2.	Right	Right	Low	Not Understanding the Concept
3.	Right	False	High	Having Misconceptions
4.	Right	False	Low	Not Understanding the Concept
5.	False	Right	High	Having Misconceptions
6.	False	Right	Low	Not Understanding the Concept
7.	False	False	High	Having Misconceptions
8.	False	False	Low	Not Understanding the Concept

RESULTS AND DISCUSSION

Analysis of the lesson topic as regards the material classification and its changes resulted in 6 indicators of competency achievement that students had to possess, namely explaining the understanding of elements, compounds and mixtures; distinguishing elements, compounds, and mixtures; determining acidic, basic and saline substances; distinguishing physical and chemical changes; explaining the homogeneous and heterogeneous mixtures; and distinguishing homogeneous and heterogeneous mixtures. The results of the analysis based on these indicators of competency achievement are shown in Table 4.

Based on Table 4, male students tended to have the biggest misconceptions on the compe-

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tency achievement indicator as regards distinguishing elements, compounds and mixtures. To distinguish elements, compounds and mixtures required good conceptual knowledge. Students who did not have good conceptual knowledge about it would have difficulty in answering questions correctly, and they would even have misconceptions. This is consistent with the results of Yamtinah's study which explains that male students tend to have lower conceptual knowledge than female students (Yamtinah, Masykuri, Ashadi, & Shidiq, 2017).

In addition, the indicators of competency achievement pertinent to distinguishing between elements, compounds, and mixtures; and determining acidic, basic and salt substances required good memory skills. (Taasoobshirazi & Carr, 2008) in their research stated that the ability to remember well tends to be owned by female students. The aforementioned research fostered the results of the identification carried out. Female students who had misconceptions on those competency achievement indicators were in the percentages of 17% and 12%, and these results were better than those of male students.

On the indicators of competency achievement with respect to distinguishing physical and chemical changes; and distinguishing homogeneous and heterogeneous mixtures, male students had low percentages of misconceptions. Those indicators required a good ability to see facts. These results prove the previous research which says that male students can make observations and see facts well (Greenfield, 1996).

The instrument used in this study could not only identify misconceptions had by students but also identify their understanding of the material classification and its changes. This was due to the addition of the CRI method to the Two-tier Multiple-Choice instrument. Students might be able to answer correctly in the first tier and gave the reason in the second tier. However, if they were not sure of their own answers, it indicated that they tended not to understand the concept well. Conversely, when students answered the first tier and second tier incorrectly, but they believed that their answers were correct, this indicated a misconception. Students who understood the concept well would answer correctly on both tiers, and they believed that their answers were correct. The analysis results of the concept mastery between male and female students on the topic of material classification and its changes are presented in Figure 1.

Based on Figure 1, it seems that more male students did not understand the concept and had misconceptions. On the contrary, female students got a higher percentage for understanding concepts. These results are consistent with the research conducted by (Greenfield, 1996). Female students have a relatively high level of science, good self-concepts namely students' perceptions of their scientific abilities, and good science laboratory participation (Greenfield, 1996). These reasons explain this study result.

The results of other studies show that there is no significant gender difference for science learning outcomes up to the age of 11 years old. In addition, gender disparities emerge much earlier in science than in mathematics. Lower science grades for girls are proven in grade 7 (Farenga & Joyce, 1999). The aforementioned result is different from the result of this study. In class VII, where the study was conducted, female students had a better understanding of the concept than male students.

Table 4. Percentages of Students' Misconceptions Based on Competency Achievement Indicators

No	The Indicators of Competency Achievement	Percentages of Students' Misconceptions (%)	
		Male	**Female**
1	Explaining the understanding of elements, compounds and mixtures	22	22
2	Distinguishing elements, compounds, and mixtures	28	17
3	Determining acidic substances, bases and salts	21	12
4	Distinguishing physical and chemical changes	19	13
5	Explaining homogeneous and heterogeneous mixtures	21	12
6	Distinguishing homogeneous and heterogeneous mixtures	16	13

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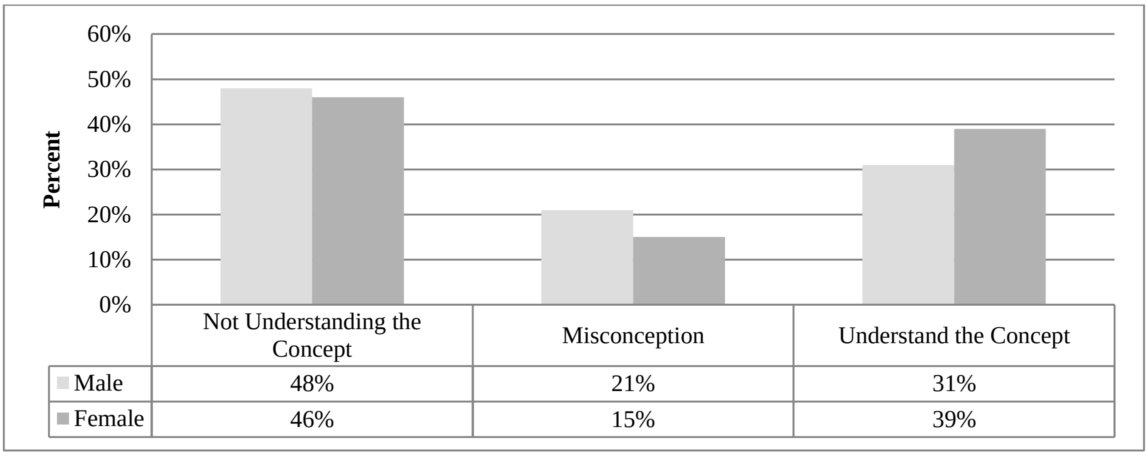

Figure 1. Graphic of Students' Conceptual Understanding

A good conceptual understanding in the field of science will cause students to be interested in science lessons. Studies conducted by researchers to see differences about students' interest in science have been done a lot. The results indicated that female students have more interest in science, but these results are not comparable to their careers in science (Jones & Levin, 1994). Female students have a lower interest in science than male students in primary school, but male students have a high curiosity in the field of science. The likelihood depicts that female students only like science in the classroom, but not for activities outside the classroom (Britner, 2008; Ilardi & Bridges, 1988; Mohammad, Shahzad, & Sohail, 2010; Saunders, Davis, Williams, & Williams, 2004; Shemesh, 1990; Winkelmann, Van Den Heuvel-panhuizen, & Robitzsch, 2008).

The profile of misconceptions between male and female students is not much different from students' achievement and interest. Research on students' misconceptions has become a central issue in science education over the past two decades because misconceptions are considered to be the root of learning problems, and barriers to instructional learning towards the acquisition of scientific concepts (Nakiboglu, 2003). Misconceptions are divided into two categories: experience and teaching. Misconceptions of experience are also called alternative, intuitive or original conceptions. In the misconceptions of experience, the concept has been understood through everyday experience and interactions with the phenomena involved. The examples of experience misconceptions occur in connection with the phenomena such as motion, energy, and gravity. However, misconceptions related to some chemical phenomena are fundamentally different because the presence of atoms and molecules does not directly exist in the realm of everyday experience. Misconceptions associated with a more abstract phenomenon as such result from several teaching experiences, inside or outside the classroom, including independent study (Skelly, 1993).

In this study, misconceptions that occurred were included in those of teaching as well as experience because the characteristics of the material classification and its changes had an abstract concept like most other chemicals. This abstract chemistry creates its own difficulties for students to understand (Coll, Ali, Bonato, & Rohindra, 2006; Taber, 2009; Tümay, 2016). In addition, students come to the classroom with ideas about many things and experiences they have experienced. They continually build their mental models to understand the world around them. Unfortunately, a large number of these models are wrong from a scientific viewpoint (Fisher & Moody, 2002). Misconceptions had by students can be caused by their experiences to interpret their ideas, culture and language (Lubben, Netshisaulu, & Campbell, 1999). Other factors can be caused by the textbook used by them (Ratnasari, Sukarmin, Suparmi, & Aminah, 2017) Misconceptions can be prevented and addressed with special chemistry teaching instructions. Chemistry lessons need to be delivered as a whole by including the levels of representation that become the characteristics of this subject. Chemistry has 3 levels of representation: *Macroscopic, Sub-microscopic,* and *Symbolic* (A H Johnstone & El-Banna, 1989; A H Johnstone, 1991; Alex H Johnstone, 1974; D. Treagust, Chittleborough, & Mamiala, 2003). By providing students' conceptual understanding through these representation levels of chemistry, misconceptions can be reduced (Gilbert & Treagust, 2009; D. Treagust, Chittleborough, & Mamiala, 2003;

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D. F. Treagust & Centre, 2001; Tyson, Treagust, & Bucat, 1999).

This study used the Two-Tier Multiple-Choice instrument equipped with CRI as a tool for identifying misconceptions. Two-Tier Multiple Choice is a set of questions that are more sophisticated than those of ordinary multiple-choice questions (Adodo, 2013). Similar to traditional multiple-choice questions, two-tier multiple-choice questions are classified into a test genre known as "objective test" or "selected response". Two-tier Multiple Choice contains two levels of questions that are interconnected. The purpose of the second tier is to encourage students to think deeply. The first tier of questions is usually related to knowledge statements, while the second tier of questions facilitates testing the reasons beyond their answers. The questions in this instrument are more facilitating to test students' level of understanding compared to conventional multiple-choice questions. The purpose of the questions in this instrument is to help students and teachers identify students' problems so that they can rethink to correct their mistakes or overcome their difficulties and develop deeper understanding (Cullinane, 2011).

According to Tan, Taber, Goh and Chia (2005), the items in the two-tier multiple-choice diagnostic instrument are specifically designed to identify alternative conceptions and misconceptions students have on a particular content (Tan, Taber, Goh, & Chia, 2005). The second tier of each item contains possible reasons for the answers provided in the first tier. This makes the diagnostic instrument more powerful and effective because it allows underlying the reasons of students' answers. The wrong reason (distractor) comes from alternative students' conceptions collected from literature, interviews and free response tests.

Two-tier diagnostic test provides the structured method to diagnose students' misconceptions more precisely, and it is suitable for large-scale surveys (Lai, 2007). Other researchers use this instrument not only to find out students' conceptions (Lai, 2007; Y. C. Lin, Yang, & Li, 2016), but also to measure higher order thinking skills (Shidiq, Masykuri, & Susanti, 2014, 2015), to measure students' cognitive abilities (Tüysüz, 2009; Wulandari, Yamtinah, & Saputro, 2015), and to improve learning effectiveness (Wang, 2014).

In addition, the combination of two-tier instrument with CRI has been proven effective in knowing students' conceptions (Diani et al., 2019; Hasan et al., 1999; Hasan, Bagayoko, & Kelley, 2016; Helmi et al., 2019). CRI (Certainty of Response Index) is the measure of respondents' confidence or certainty level in answering each question given. The CRI identification method is used to identify the occurrence of misconceptions, and it is also able to distinguish them from the students who do not understand concepts. CRI is based on a scale of 0 to 5 that describes respondents' confidence in answering each question. The level of certainty of the answers is reflected on the CRI scale. Low scale indicates the respondents' unconfident in the concept while answering a question. In this case, the answer is usually determined only on the basis of guessing. On the other hand, a high CRI reflects a high confidence and certainty in the respondents' concept while answering the question. In this case, the element of guessing is very small. A respondent who has misconception or does not understand the concept can be distinguished simply by comparing whether the answer to a question is correct or not with how high or low the degree of confidence is in answering (Hasan et al., 1999).

CONCLUSION

Misconceptions that occur to students can inhibit the acquisition of new information. Therefore, identification of students' misconceptions to avoid the adverse effects that are resulted needs to be done. On the topic of material classification and its changes, misconceptions are identified. These misconceptions result in differences between male and female students. Female students tend to have misconceptions on the competency achievement indicator as regards explaining the understanding of elements, compounds and mixes, while male students tend to have misconceptions on competency achievement indicator appertaining to differentiating elements, compounds, and mixtures. In general, female students have better conceptual knowledge than male students. The two-tier multiple-choice instrument can be used as an alternative instrument to identify misconceptions among students. The results of this study are expected to be a reference for educators to identify and resolve students' misconceptions.

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