J_Analysis of misconceptions of chemicalbonding among tenth grade senior highschool students using a two-tier test

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Analysis of Misconceptions of Chemical Bonding among Tenth Grade Senior High School Students Using a Two-Tier Test

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Abstract. Chemical bonding is among the material required to be taught to tenth grade senior high school students. This topic also is directly related to other concepts concerning chemicals, such as the shape of molecules and chemical reactions that are associated with the forming or breaking of bonds in a chemical reaction. Unfortunately, chemical bonding is an abstract concept for learners to grasp and this can lead to misconceptions. Errors in understanding this concept can interfere with the learning of other interrelated concepts, so these misconceptions need to be detected in order to derive a solution. This research analyzed the percentage of learners with misconceptions of chemical bonding using a two-tier test totaling three questions. In all, 180 students participated in this study, divided into different school levels (high, medium, low) based on national test scores for chemistry in 2016. The students who participated in this study were recruited using stratified random sampling. More than 50% of learners experienced misconceptions. The level of students' conceptual understanding of chemical bonding shows a common failure in many aspects of chemistry teaching. The highest percentage of students with misconceptions was attending the high-level school. Such misconceptions are due to the failure of many aspects, not only the teaching. Therefore, we need to try to find a solution to reduce misconceptions.

Keywords: conceptual understanding, misconceptions, students' understanding.

INTRODUCTION

Schools make numerous and important contributions to their learners, one of which is to provide useful information for learners and for their lives later in their communities. This information is usually conveyed by teachers and thus within the scope of schooling, teachers have a share in the process of providing information as a part of their teaching. Information is delivered through the lesson material and is generally divided into various forms of learning.[1] In the application of teaching in schools, most teachers are pursuing targets and are constrained in terms of time to complete the subject matter because they are bound by the curriculum applicable in each school and the need to move on to the next lesson material to be taught.[2] Therefore, teachers often do not realize that the most important aspect of teaching is determining that learners have understood the concepts within the material taught. Most teachers only focus on the standards that each learner must achieve and do not identify whether learners who have high scores really understand the material or are just guessing the answers in the same way as learners who have low scores.[3-5]

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Among the compulsory subject matter to be taught to tenth grade senior high school students taking science majors is chemistry.[6] In the chemistry course, there is a considerable body of material that addresses important and interrelated concepts.[7] One such concept is chemical bonding, which is structured and linked to other concepts concerning chemicals, such as equalizing chemical reactions, ionizing electrolyte solution, the acid-base reaction and chemical reaction.[8] Educators must consider these linkages and take care in teaching their students, ensuring that they have absorbed the concepts properly and correctly. Learners' lack of understanding and the educator's lack of awareness of their failure to understand will cause major problems and errors, often due to misconceptions.[9]

Misconception is a term that describes a misstep in knowledge that the learner possesses that is incorrect from the expert perspective of a concept. Such inappropriate concepts can be stored in the learners' memory for long periods of time and may even be transmitted in the future.[5]This can result in a decline in the cognitive process (way of thinking) or knowledge of learners dating back to the past and over the long term.[10] Misconceptions must therefore be avoided because they have links to other materials and understanding of concepts. Therefore, both teachers and learners should have a way of detecting misconceptions so that there will not be any more serious problems in the future. One way of detecting misconceptions is through a two-tier multiple-choice test.[11]

The two-tier multiple-choice test asks questions that are able to diagnose learners' understanding, structured in two levels: The first level contains core questions or very important questions with four to five response options, while the second level addresses the reasons or explanations for the responses at the first level.[12]Two-tier multiple-choice diagnostic questions are usually analyzed through a table showing the answers given by learners at each level. Each student's answers, both first-tier and second-tier, are combined and classified according to the degree of understanding of the learner. The learners' answers can be categorized as follows[13, 14]:

- Understanding of the concept, based on the criteria answered correctly (first tier) and the explanation indicating the concept has been mastered (second tier).
- Misconception, based on the criteria answered correctly (first tier) but the explanation is incorrect or illogical (second tier).
- No understanding, based on the criteria answered incorrectly (first tier) and the explanation is incorrect or illogical (second tier).

A study was conducted in 2017 on misconceptions of chemical bonding using a two-level test instrument, but the study compared learners at different levels of education, high school and college students[15], resulting in an imbalance in the results obtained. Thus, this study has been undertaken with subjects at the same level of education, only differing at the level of school grades. The differences between the schools were based on achievement in the 2016 National Examination of chemistry in Indonesia. The study recruited subjects from schools at different levels of attainment because it was assumed that school-level differences would have an impact on academic achievement.[16] Therefore, this study aimed to test whether learners at schools with different grade levels would present misconceptions of chemical bonding and compare the percentage levels of learners' understanding at the three different levels of high school. The diagnosis and comparison can be used as evaluation material for teachers to develop better teaching methods and for educators to address how learners are assessed in terms of conceptual understanding.

METHOD

Research Design

This research was conducted using a quantitative descriptive technique, analyzing data in the form of numbers, namely scores and percentages obtained using two-tier instruments distributed to high school students at different grades of school. The implementation of the data collection instrument in this study aimed to identify information on misconceptions and took the form of a diagnostic tool comprising three questions at two tiers.

Population

The population in this research encompassed all students in tenth grade at state senior high schools in Sleman Regency in the academic year 2017/2018.

Sample and Sampling Techniques

The total sample in this study comprised 180 participants drawn from 3 public high schools in Sleman district of different levels—high, medium, and low categories—based on the chemistry scores in the 2016 National Examination. Sampling was done using the stratified-cluster random sampling technique, which is appropriate if the objects to be researched or the source data are in the same region (cluster), for the instance the population of a province or district, but the data source is heterogeneous and unequally stratified.[17] The sampling technique was used in this study because the population members met different criteria and were stratified, viewed at the school level, based on the pure chemistry scores for the 2016 National Examination.

Data Analysis

To calculate the means and frequencies of each answer, we used MS Excel. The data collection instrument in the form of two-tier multiple choice questions was validated theoretically and empirically and was thus appropriate for measurement at the time of the research. Of the 17 state senior high schools in Sleman district, 3 were selected: 1st Kalasan State Senior High School (high level); 1st Prambanan State Senior High School (medium level); 1st Ngaglik State Senior High School (low level). In each school, two classes were included. The students' answer patterns can be categorized into three levels of understanding as shown in Table 1[13, 14], which presents the results for students' answers by category: understanding, misconception, and no understanding. The data are then converted into percentage form and depicted graphically.

TABLE 1. Categories of Learners' Answers

Student's Answer Patterns	Categories of Understanding Level
The test core answer is correct - the reason is right	Understand (U)
The core test answers are correct - wrong reasons	Misconceptions (Mi)
Core test answers are wrong - wrong reasons	Do not understand (DU)

RESULTS

The participants (N = 180) were given two-tier questions on the sub-material of the stable electron array. This sub-material is the most basic and important aspect to be taught in the subject matter concerning chemical bonding. The percentage values for understanding are presented in Table 2.

TABLE 2. Student Test Results Based on Answer Patterns

No	Concept description	Answer Pattern					
		Understand (U)		Misconception (Mi)		Do not Understand (DU)	
		Total	%	Total	%	Total	%
1	Atoms in the free state are unstable, except the atoms of the noble gases. In order to attain stability, these atoms must bond with other atoms to form compounds in order to maintain their structure with relatively little energy.[18]	0	0%	103	57%	77	42%
2	The atoms of the noble gases have stabilized because the electron configuration is full[19]. The stability of the atom can be demonstrated by the difficulty of reacting elements with other elements.[20]	10	5,5%	15	8,3%	155	86%
3	To achieve stability, an element must bind to another atom by means of the use of electrons together with the same or different elemental elements.[18,21] The stability of the hydrogen atom is achieved when it binds covalently to another elemental atom without releasing an electron owned.[22,23]	9	5%	18	10%	153	85%

As can be observed, the highest percentage is in the category "no understanding," indicating that 86% of learners overall are unable to answer questions correctly concerning an atom's tendency to achieve stability. These overall percentages are then calculated based on the number of learners in each category in different schools. The results of the analysis are presented in Table 3.

TABLE 3. The results of the analysis

	High school with the high level			
Number of learners (N= 53)	**Question Number**	**Understand (U)**	**Misconceptions (Mi)**	**Don't Understand (DU)**
	1	0 %	90.57 %	9.43 %
	2	5.67 %	13.20 %	81.13 %
	3	13.21 %	1.89 %	84.90 %
	High school with the middle level			
Number of learners (N= 67)	**Question Number**	**Understand (U)**	**Misconceptions (Mi)**	**Don't Understand (DU)**
	1	0 %	70.15%	29.85 %
	2	8.96 %	7.46%	83.58 %
	3	1.50 %	23.88%	74.62 %
	High school with the low level			
Number of learners (N= 60)	**Question Number**	**Understand (U)**	**Misconceptions (Mi)**	**Don't Understand (DU)**
	1	0 %	11.67 %	88.33 %
	2	1.67 %	5 %	93.33 %
	3	0 %	1.67 %	98.33 %

In addition to the high percentage for incomprehension, there is an extremely high percentage for misconception. The percentages of the average number of misconceptions in each school are summarized in Fig. 1 and categorized in Table 4.

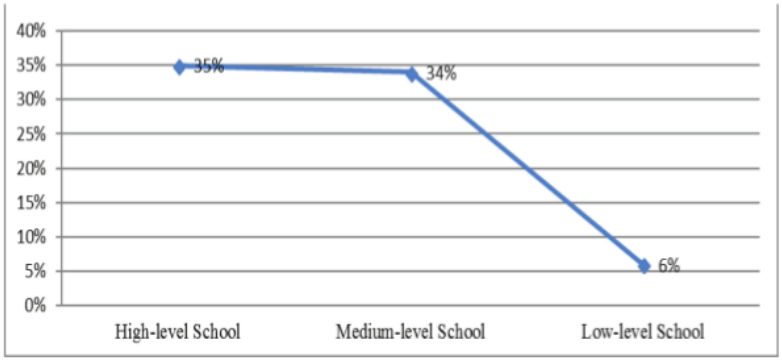

FIGURE 1. Percentage of Misconception of Different High School Level.

TABLE 4. Category of Misconceptions

Percentage	Category
0 < Misconception ≤ 30	Low
30 < Misconceptions≤ 70	Medium
70 < Misconceptions≤ 100	High

As can be seen, the school with the lowest percentage of misconceptions of chemical bonding among students is the low-level high school at 6%, followed by the mid-level high school at 34%, and a very slightly higher percentage for the high-level high school at 35%.

DISCUSSION

The concepts of chemical bonding tested included the following: "The tendency of elements in nature is not in a state of freedom," "The stability of noble gas group elements," and "The atomic tendency of an element to achieve stability." The results of the identification of misconceptions on the subject of chemical bonding are discussed in turn.

The tendency of elements in nature is not in a state of freedom

Based on the results of the research, there are misconceptions concerning the concept of the tendency of elements in nature not to be in a state of freedom, tested by question 1. In all, 57.46% of learners experienced misconceptions and 42.54% of learners did not understand the concept. In question 1, students were asked to consider how atoms are free to achieve stability and the correct answer was through being attached to other atoms. The correct concept was then accompanied by reasons that could support the statement, indicating whether students identified the correct answer at the first tier but based on a misconception of the underlying concept at the second tier. The correct reason supporting the concept was the formation of a compound so the structure will be maintained with relatively little energy.[18] Students experiencing misconceptions knew that the atoms must form compounds by binding to other atoms to achieve stability, but when asked why they should form compounds, learners were confused and did not know that by forming a compound the atoms would tend to expend relatively little energy. Most learners answered on the grounds that by forming the compound, a valence electron pair of bonded atoms would form. The statement is correct, but not appropriate if it is used as a supporting reason for the first-level question.

The stability of noble gas group elements

Based on the results, there are misconceptions and a lack of understanding concerning the concept of the stability of noble gas group elements tested by question 2. Indeed, while 8.55% of learners held misconceptions, an overwhelming 86.01% of learners did not understand the concept. With regard to question 2, learners did not understand that the cause of the noble gas atoms being stable is because the electron configuration is so full that it is difficult for there to be a reaction with other elements, i.e., noble gas atoms cannot react with the atoms of other elements. The difficulty here appears to be the word "react," for example with regard to XeF_2 molecules. Xe is a noble gas class element but can still bind to other elements, forming compounds[24,25]. Based on the misconceptions among the learners, we can draw the conclusion that they are unable to define the concept correctly. Moreover, this can also explain why the percentage of learners lacking understanding is the highest.

The atomic tendency of an element to achieve stability

Based on the results, there are misconceptions regarding the concept of the atomic tendency of an element to achieve stability tested by question 3, but even more so a lack of understanding. Thus, while 9.15% of learners held misconceptions, 85.95% of learners did not understand the concept at all. In question 3, the learners also did not

understand that a hydrogen atom with atomic number 1 will achieve stability by using the same or different electrons to form a bond called a covalent bond. In this study, the learners' response was that the hydrogen atom must bind to another atomic element with a valence electron of 7 such as F, Cl, Br, or I. The learners considered that to achieve stability an atom must meet the octet rule of having 8 valence electrons, but octet rules do not always apply in all cases. H_2 is one example of a compound that does not follow the octet rule.[26]

In the concepts examined, more than 50% of learners held misconceptions and more than 80% of learners did not understand the concept tested. It is thus extremely important that teachers and learners be aware of these issues. The application of the two-tier instrument proved effective in detecting not only misconceptions but also the ability of learners to understand concepts. Indeed, 57.46% is a rather high percentage and stunning when viewed in terms of being categorized "medium" in terms of misconception. Such a large percentage should not be considered trivial as it may affect students' performance in learning other related material. Therefore, there is a need to identify a way to reduce misconceptions and the lack of learners' understanding.

RECOMMENDATIONS

Teaching the abstract concept of chemical bonding is a challenge for teachers in schools, particularly in view of the fact that learners have different abilities in understanding such concepts. Teaching abstract material in a step-by-step manner, from the simple to the complex, has been perceived as a means of helping learners improve their understanding. However, identifying the misconceptions held by students and their level of (lack of) understanding is very important because it can prevent the emergence of new misconceptions concerning interrelated materials. In addition, teachers can also evaluate what methods or forms of teaching can prevent both misconceptions and a lack of understanding on the part of learners, and the two-tiered approach is one effective way of preventing the occurrence of such misconceptions or misunderstandings.[8]

The results of the study point to the fact that students' cognitive structure demonstrates the inadequacy of knowledge and misconceptions in relation to chemical bonding, and that this an important issue that must be considered. There are issues here with the course books used (including diagrams), teachers' inadequacies in terms of instructional methods and techniques, aspects students bring to the learning environment, and overgeneralization, all of which can be the causes of misconceptions. Certain points should be taken into consideration when teaching topics such as chemical bonding. For example, the content and context should be prepared to facilitate students' learning of scientific knowledge, such as that related to chemical bonding. Advance organizers, such as concept maps and conceptual frameworks, should be used at the beginning of the course of study to determine students' prior knowledge and possible knowledge inadequacies or misconceptions. Also, these advance organizers will encourage students to establish connections between concepts. Important concepts should be listed at the end of each chapter in course books, and a sample concept map containing the concepts should be added to the end of each chapter. Moreover, connections between concepts should be emphasized during lessons and these can be highlighted in course books. This will ensure that students make connections between concepts in a coherent manner, helping them organize the knowledge elements with regard to related subjects. For individuals, having scientific knowledge of individual concepts will encourage the development of complex organized knowledge regarding multiple phenomena.

CONCLUSION

Examining sub-material concerning a given problem shows that more than 50% of learners hold misconceptions. This is a rather high percentage and therefore it is necessary for teachers to make efforts to redress these. What is notable is that the highest percentage of students with misconceptions was identified in the high-level school, i.e., the 1st Kalasan State Senior High School. Such misconceptions are a form of failure with regard to many parties, not just teachers who solely teach. Indeed, teachers, students, and those responsible for education more broadly need to try to find solutions that will reduce such misconceptions. One of these is meaningful teaching that can be understood by both teachers and students.

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