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Decoding Misconceptions in Thermochemistry: Insights from the Four-Tier Diagnostic Test

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ABSTRACT

Purpose of the study: The purpose of this study was to determine whether or not there were student misconceptions and their causes, as well as to determine the percentage of student misconceptions on thermochemistry material measured using the Four-Tier Diagnostic Test Instrument.

Methodology: This research is a descriptive study where the sample in this study was taken using purposive sampling technique. The subjects in this study were students of grade XI and XII of State Islamic High School 1 Pekanbaru. Data collection techniques used in this study were the Four-Tier Diagnostic Test, observation, interviews and documentation.

Main Findings: The study revealed 4% of grade XI and 13% of grade XII students had misconceptions in thermochemistry. Misconceptions were higher in grade XII for basic concepts (19.7%) and reaction types (13.4%), while grade XI struggled more with enthalpy calculations (6.3%). Understanding remained limited across key concepts.

Novelty/Originality of this study: It can help increase teachers' insight in the teaching and learning process, so that teachers are more aware of the explanation of the material that sometimes makes students wrong and experience misconceptions. In addition, teachers can also provide follow-up to students if misconceptions occur.

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1. INTRODUCTION

Current school learning refers to the Independent Curriculum which emphasizes a student-centered learning approach [1], [2]. In this system, students are required to actively build an understanding of concepts independently [3], [4]. This is a challenge in itself, especially in understanding abstract and hierarchical chemistry material. Students often have difficulty imagining the shape of particles such as atoms, ions, and molecules that cannot be observed directly. If the basic concept is not understood correctly, it has the potential to cause misconceptions that will continue in subsequent materials [5], [6].

Chemistry is a subject taught in high schools with complex material characteristics [7], [8]. Chemistry material is generally abstract and requires a hierarchical understanding of concepts. Many students have difficulty understanding the characteristics of invisible substances or chemical reactions [9], [10]. Students' inability to understand these concepts causes them to construct erroneous understandings. These misunderstandings are called misconceptions [11], [12].

Hammer states that misconceptions are initial understandings that are not in accordance with scientific concepts and are formed from students' personal experiences. Teachers have an important role in recognizing misconceptions experienced by students in order to develop appropriate learning strategies [13], [14]. Misconceptions need to be identified early so that they do not continue to be carried over into the learning process [6], [15], [16]. If misconceptions are not immediately corrected, they will become an obstacle in understanding more complex chemical concepts [17], [18]. Therefore, misconception analysis is an important initial step in improving the quality of chemistry learning [19], [20].

In the world of education, misconceptions are defined as students' misunderstanding of concepts that are not in accordance with scientific views [21], [22]. Misconceptions describe students' difficulties in understanding concepts that differ from scientific consensus [23], [24]. Misconceptions often occur because of a mismatch between students' prior knowledge and the concepts being taught [25], [26]. Inaccurate prior knowledge of students can be an obstacle in the process of constructing new knowledge. Therefore, it is important for teachers to explore students' prior knowledge before conveying more advanced concepts.

Misconceptions can stem from students' failure to integrate prior knowledge with correct scientific concepts [14], [27]. Van Den Berg emphasized that misconceptions that are left unchecked will have a negative impact on student learning. Especially if the misconception lasts a long time and is not realized by students or teachers [5], [28]. Students who experience misconceptions will have difficulty understanding advanced concepts [29]. This results in a decrease in student motivation and learning achievement in chemistry.

One effective way to identify misconceptions is through diagnostic tests. This test can provide an overview of conceptual errors that students have based on answer choices and their reasons. Diagnostic tests can be used before or after learning to map student understanding [30], [31]. One form of a more in-depth test is the four-tier diagnostic test. This test is able to explore not only students' answers, but also their reasons and level of confidence in choosing answers.

Thermochemistry material is one of the essential concepts in chemistry learning that is a prerequisite for understanding other concepts, such as equilibrium and reaction kinetics [32], [33]. However, this material is often considered difficult by students because it involves many formulas and abstract concepts. This difficulty causes low student interest and the emergence of various forms of misconceptions [34], [35]. Several studies have found student misconceptions related to the differences between temperature and heat, systems and environments, and endothermic and exothermic reactions [36], [37]. Therefore, it is important to analyze misconceptions in thermochemistry material using the four-tier diagnostic test instrument to get an accurate picture of student understanding.

Irfandi et al., [38] research identified and analyzed students' misconceptions in thermochemistry material using a three-level diagnostic instrument, which focused on measuring students' understanding through multiple choices with reasons. Shiddiqi et al., [39] research conducted a systematic literature review to analyze the problem of misconceptions and diagnostic instruments used in chemistry learning in general, providing a holistic view of various approaches to identifying misconceptions. Unlike the two studies, the current study used a four-level diagnostic instrument, which offers a more in-depth approach by including students' level of confidence in their answers. This approach not only identifies misconceptions but also measures students' level of confidence, providing a more comprehensive insight into understanding conceptual errors in thermochemistry material. Thus, this study bridges the gap between specific misconception identification and a holistic approach by measuring confidence as an additional dimension.

This study offers novelty by using a four-tier diagnostic test to analyze students' misconceptions in thermochemistry, an approach that has not been widely applied in previous studies. This instrument not only identifies misconceptions but also evaluates students' level of confidence in their answers, providing a more comprehensive understanding of students' mindsets. The urgency of this study lies in the high level of students' misconceptions in basic thermochemistry concepts, which can hinder their understanding of advanced chemistry concepts. By providing more in-depth data, this study can be the basis for developing more effective and innovative learning strategies in correcting students' misconceptions, while improving the quality of chemistry learning in schools. The purpose of this study was to determine whether or not there were student misconceptions and their causes, as well as to determine the percentage of student misconceptions on thermochemistry material measured using the Four-Tier Diagnostic Test Instrument.

2. RESEARCH METHOD

2.1. Type of Research

The type of research used is descriptive research and uses a qualitative approach. The aim is to be able to explain the misconceptions that occur and the factors that cause these misconceptions. The purpose of the qualitative approach is that data in the form of oral or written data is easy to process.

2.2. Population and Sample

The population is all students of grade XI and XII Natural Sciences of Madrasah Aliyah Negeri 1 Pekanbaru. Samples were taken from one grade XI and one grade XII. This sampling aims to determine the comparison of student learning outcomes based on their learning methods (online learning and offline learning). To determine the sample, a purposive sampling technique was used which took samples based on certain considerations [40], [41].

2.3. Data Collection Techniques

The data collection technique used in this study is a test. This test has 4 stages, namely: the first stage is in the form of multiple choice questions, the second stage is the confidence level or level of belief regarding the first stage, the third stage is the reason related to the answer to the first stage chosen, and the fourth stage is the confidence level again related to the reasons given in the third stage. This test consists of the concept of ΔH as the heat of reaction at constant pressure and its function in thermochemical equations, various types of enthalpy reactions (enthalpy of combustion, enthalpy of formation, and others), the concept of bond energy and Hess's law. In this test, the CRI (Certainty of Response Index) model is used, namely a measure of the level of certainty or confidence of a person to answer the questions given.

2.4. Data Analysis Techniques

The data results from the Four-Tier Test study were processed and analyzed descriptively to determine misconceptions in Thermochemistry material that occurred in students of grades XI and XII of Natural Sciences. Students' misconceptions were grouped based on the first stage in the form of multiple-choice questions, the second stage was students' confidence in answering questions, the third stage was the level of reasoning from the results of the answers in the first stage and the fourth stage was the level of students' confidence in giving reasons. The four stages are always related, in order to analyze them, the results of the four stages must be identified sequentially. The criteria for grouping misconceptions in this study can be explained as follows: The first stage is objective questions, where the correct answer is included in the correct question criteria, while the wrong answer will be included in the wrong question criteria. Can be seen in table III.1 grouping misconceptions in the first stage.

Table 1. First Stage Grouping Criteria

Criteria
True
False

The second stage is the level of confidence in answering the first stage. It can be explained in table 2.

Table 2. Second Stage Grouping Criteria

First Stage	Second Stage
True	High
True	Low
False	High
False	Low

The third stage is the level of reason or belief that exists based on the answers related to the first stage. Can be seen from table 3.

Table 3. Third Stage Grouping Criteria

No.	First Stage	Tahap Kedua	Tahap Ketiga
1.	True	High	True
2.	True	Low	True
3.	True	Low	False
4.	True	High	False
5.	False	Low	False
6.	False	Low	True
7.	False	High	True
8.	False	High	False

The fourth stage is the level of students' beliefs or reasoning related to the reasons given in the third stage. In this fourth stage, data can be seen and analyzed as well as groupings of students who do not understand the

concept, experience misconceptions or understand the concept. That is the advantage of the four-tier diagnostic test which can be seen in Table 4.

Table 4. Grouping of Misconceptions

No.	The first stage	Second Stage	Three Stage	Fourth Stage	Category
1.	True	High	True	High	Understand
2.	True	Low	True	Low	Don't Understand the Concept
3.	True	High	True	Low	
4.	True	Low	True	High	
5.	True	Low	False	Low	
6.	False	Low	True	Low	
7.	False	Low	False	Low	
8.	True	High	False	Low	
9.	False	Low	True	High	
10.	True	False	Low	High	Misconception
11.	True	High	False	High	
12.	False	High	True	Low	
13.	False	High	True	High	
14.	False	High	False	Low	
15.	False	Low	False	High	
16.	False	High	False	High	

The formula used to determine the percentage of students who understand the concept or experience misconceptions can be seen as follows:

$$P = \frac{S}{Js} x\ 100\%$$

Description:
P: Percentage of students with misconceptions
S: Number of students with misconceptions
Js: Total number of students taking the test

Next, the step taken after calculating the percentage of students is to group the misconception criteria which can be seen in table 5.

Table 5. Misconception Criteria

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

3. RESULTS AND DISCUSSION

3.1. Results of Student Misconception Analysis

Table 6. Percentage of Misconceptions of Grade XI and XII Students on Thermochemistry Concepts

No.	Thermochemical Concepts	Grade XI	Grade XII
1.	Early concepts of thermochemistry	3.6%	19.7%
2.	Exothermic and endothermic reactions	3.1%	13.4%
3.	Calculation of enthalpy, enthalpy changes, thermochemical equations, and energy diagrams	6.3%	2.0%
	Total Misconception	4%	13%

This study was conducted to determine the level of students' misconceptions in thermochemistry material using the four-tier diagnostic test instrument. The results of the analysis showed that 4% of grade XI students experienced misconceptions, while 12% of grade XII students showed a higher level of misconceptions, namely 13%. This shows that even though grade XII students have had more learning experience, misconceptions still occur and tend to increase. This indicates the need for a more effective learning approach in overcoming misconceptions that occur early on.

In more detail, in grade XI students, misconceptions are divided into several concepts. As many as 3.6% of students experience misconceptions in the basic concept of thermochemistry, 3.1% in the concept of exothermic and endothermic reactions, and 6.3% in the concept of enthalpy calculations, enthalpy changes, and thermochemical equations and energy diagrams. On the other hand, grade XII students showed higher misconceptions in the initial concept of thermochemistry, which was 19.7%, and 13.4% in the concept of exothermic and endothermic reactions. However, in the aspect of enthalpy calculations and energy diagrams, only 2% of grade XII students experienced misconceptions, indicating an increase in understanding in the calculation aspect compared to grade XI.

3.2. Discussion of Misconceptions Based on Concepts

High misconceptions in the initial concept of thermochemistry indicate that students have difficulty in understanding the basic concepts of enthalpy and energy changes in chemical reactions. This can be caused by the lack of visual representation or concrete analogies in the learning process. The concept of invisible and abstract energy is a major obstacle in understanding thermochemical events. In the concept of exothermic and endothermic reactions, misconceptions arise because students often equate temperature with heat, and have difficulty distinguishing between the system and the environment in chemical reactions. This finding is in line with the results of previous studies that stated that misconceptions commonly occur in the basic concept of thermochemistry (Ida & Sugiati, 2017).

Interestingly, the results of the analysis show that in the concept of calculating and using thermochemical formulas such as Hess's law, grade XII students actually show lower misconceptions than grade XI students. This shows an improvement in understanding mathematical and procedural concepts as the level of education increases. However, it should be noted that procedural understanding does not necessarily reflect a complete conceptual understanding. Therefore, it is important to ensure that students are not only able to calculate, but also understand the scientific meaning of the calculated enthalpy changes.

3.3. Implications of the Four-Tier Diagnostic Test Instrument

The use of the four-tier diagnostic test instrument in this study has been proven to be able to reveal students' misconceptions in more depth. With four layers of assessment—answers, reasons, and two levels of confidence—teachers can obtain information not only on whether students answered incorrectly, but also on how confident they are with their answers. Students who answer incorrectly with high confidence are a strong indication that they have misconceptions. Conversely, students who answer correctly but are not confident indicate that they may be guessing or have not fully understood the concept. Therefore, this instrument is very useful in designing more targeted learning interventions.

3.4. Follow-up on Misconceptions

From the results of this study, teachers are advised to conduct early detection of student misconceptions, especially in the initial concept of thermochemistry which has the highest level of misconception. Teachers can use the results of this diagnosis as a basis for developing more contextual learning strategies, using visual media or simulations to help students understand abstract concepts. In addition, guided discussions and an emphasis on understanding concepts before performing mathematical calculations can also minimize the occurrence of further misconceptions. These results can also be used in the development of teaching materials or special remedial modules to strengthen student understanding.

Misconceptions in basic thermochemistry concepts indicate that students have difficulty understanding concepts such as enthalpy and energy changes in chemical reactions. This may be due to the lack of visualization or concrete analogies during the learning process. Abstract concepts such as energy often require a visual approach to help students understand them. If not addressed, misconceptions at this early stage can affect students' understanding of more advanced concepts. Therefore, emphasizing basic concepts in learning is an important first step.

In the concept of exothermic and endothermic reactions, the misconception that often arises is the wrong understanding of the difference between heat and temperature. Many students also have difficulty distinguishing between the system and the environment in a chemical reaction. This reflects the need for more exploratory and contextual learning, such as the use of simulations or experiments that highlight the interaction between the system and the environment. With this approach, students can better understand the thermochemical properties of the chemical reactions they are studying.

Although there was an increase in understanding in grade XII students regarding the calculation of enthalpy and the use of formulas such as Hess's law, more attention is needed to ensure that this understanding is not only procedural. Conceptual understanding should be emphasized, such as the relationship between enthalpy change and the energy involved in a reaction. Teachers can integrate concept-based learning with mathematical calculations to ensure that students understand the scientific meaning of each step of the calculation.

The use of a four-level diagnostic instrument provides in-depth insight into how students understand a concept. This instrument allows for the detection of misconceptions based not only on incorrect answers but also on the level of student confidence. This information is very useful for teachers to design more targeted learning strategies. By utilizing data from this instrument, teachers can identify concepts that need the most attention and develop more effective learning approaches.

The results of this study emphasize the importance of early detection of student misconceptions, especially in basic concepts that tend to have high levels of misconceptions. Interactive learning strategies, such as guided discussions, the use of visual media, and computer simulations, can help students build better understanding. In addition, focusing on understanding before entering the mathematical calculation stage can help students overcome misconceptions early on.

Visual-based learning media, such as energy diagrams or chemical reaction animations, can be very effective tools in explaining abstract concepts. Computer simulations showing the interaction between the system and the environment in exothermic and endothermic reactions can also help students understand the concept better. The combination of visual media and interactive explanations allows students to see the direct relationship between theory and practice.

This study opens up opportunities to develop more targeted and effective learning materials. Learning modules that include strategies to overcome misconceptions, such as concept-based tasks and structured laboratory activities, can improve students' understanding. In addition, remedial materials based on diagnostic results can be an important step in correcting students' misconceptions. Thus, this study not only provides insight into misconceptions but also offers practical guidance to improve the quality of chemistry learning.

This study has several limitations that need to be considered. First, the study sample was limited to students at a certain level, so the results may not be fully representative of the wider student population. Second, the four-level diagnostic instrument used, although effective, requires more time and attention from students to fill in, which may affect their concentration levels during the data collection process. Third, this study only focused on a specific concept in thermochemistry, so it does not provide a complete picture of students' misconceptions in other chemistry topics. In addition, the analytical approach only covers the identification of misconceptions without assessing the effectiveness of specific learning methods to address them. This limitation opens up opportunities for further research that can expand the scope of the topic, involve a larger population, and evaluate learning interventions directly.

4. CONCLUSION

The conclusion of this study is that the average percentage of the level of understanding of class XI students on thermochemistry material is 27.5%, students who experience misconceptions are 4.2% and those who do not understand the concept are 68.3%. While the level of understanding in class XII students is 5.6%, students who experience misconceptions are 13.3% and those who do not understand the concept are 81.1%. Further research can expand the scope by evaluating students' misconceptions in other chemistry topics using a four-tier diagnostic instrument to compare misconception patterns across concepts. In addition, experimental research is needed to test the effectiveness of a four-tier diagnostic outcome-based learning strategy in significantly reducing students' misconceptions.

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