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Identification of Grade XI Students' Misconceptions on Thermochemistry Using a Five-Tier Diagnostic Test at SMAN 2 Siak Hulu

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Abstract

Misconceptions in thermochemistry remain a persistent challenge in chemistry education because they can impede conceptual understanding and adversely affect learning outcomes. This study aimed to identify Grade XI students' misconceptions about thermochemistry and determine their underlying sources using a five-tier diagnostic test at SMAN 2 Siak Hulu. A descriptive quantitative design was employed, involving 100 students from Classes XI-4, XI-5, and XI-6 who had studied thermochemistry. Data were collected using a 15-item five-tier diagnostic test covering seven thermochemistry concepts and supplemented with structured interviews. The findings revealed misconceptions across all seven concepts, with an average prevalence of 18%, categorized as low. The highest prevalence was identified for thermochemical equations (23%), whereas the lowest was found for heat and energy (9%). Students' own reasoning was the predominant source of misconceptions (82.13%), followed by textbooks, teachers, peers, and the internet. These findings demonstrate the utility of the five-tier diagnostic test in identifying misconceptions and tracing their underlying sources. The study provides an empirical basis for teachers to develop targeted instructional strategies that prevent and remediate misconceptions, thereby strengthening students' conceptual understanding of thermochemistry.

Keywords: Chemistry Education; Conceptual Understanding; Five-Tier Diagnostic Test; Misconceptions; Thermochemistry

INTRODUCTION

Education serves as a crucial means of enhancing the quality of human resources. Through education, students are expected to develop critical, logical, and systematic thinking skills to address various challenges. Chemistry is one subject that plays a vital role in fostering these abilities. Chemistry instruction requires students to grasp complex and abstract concepts while engaging with interconnected mathematical calculations. Consequently, a deep understanding of concepts is essential for students to fully master the subject matter (Permatasari et al., 2022).

A common issue in chemistry education is the occurrence of misconceptions. Difficulties in grasping concepts can lead students to develop misconceptions (Fajari, 2020). A misconception is defined as a student's understanding that deviates from the scientifically correct concept and tends to be stubbornly held despite being erroneous (Isnaini et al., 2024). Alternative terms for misconceptions include non-scientific beliefs, alternative conceptions, or conceptual misunderstandings (Hardianto et al., 2025). Misconceptions differ from a mere lack of knowledge because students feel confident in their understanding, even though it is incorrect. A misconception arises when a conceptual misunderstanding is accompanied by a strong conviction (Izza et al., 2021). If not promptly identified and rectified, misconceptions can negatively affect the understanding of subsequent, interconnected chemistry concepts (Mukhlisa, 2018).

Deeply ingrained misconceptions can hinder the acceptance of correct scientific concepts, as students tend to cling to their initial, erroneous understandings (Ermawan et al., 2025). This situation not only impedes the learning process moving forward but also results in poor student learning outcomes (Faizah, 2016). Misconceptions can stem from various factors, such as teacher explanations, textbooks, internet information, or the students' own flawed prior understanding (Setyarini & Admoko, 2021). Therefore, accurately identifying misconceptions is a crucial initial step toward improving the quality of instruction. Such identification serves not only to assess students' levels of understanding but also to provide a foundation for designing instructional strategies capable of effectively correcting conceptual errors.

Thermochemistry is a chemistry topic prone to misconceptions. It deals with the energy changes accompanying chemical reactions, encompassing concepts such as systems and surroundings, exothermic and endothermic reactions, enthalpy change (ΔH), Hess's Law, and bond energy. These concepts are abstract and require students to integrate theory, mathematical calculations, and real-life phenomena, making them often difficult for students to grasp (Habibie, 2025). Failure to address misconceptions in this area promptly can hinder students' ability to understand advanced chemistry topics related to energy and chemical reactions.

Previous studies indicate that thermochemistry is a topic frequently associated with misconceptions. Research by Siregar & Adinda, (2025), utilizing a three-tier multiple-choice diagnostic test, revealed that students harbored misconceptions regarding exothermic and endothermic reactions, enthalpy change (ΔH), and Hess's Law. Similarly, a study by Windana et al., (2026) identified misconceptions concerning systems and surroundings as well as reaction energy changes through the use of a three-tier diagnostic test. Studies employing four-tier diagnostic tests conducted by Amalia & Sukarmin, (2026) demonstrate that, despite some students grasping the concepts, a significant percentage of misconceptions regarding thermochemistry persists. These findings suggest that the prevalence of misconceptions in thermochemistry remains high, necessitating in-depth identification to ensure they are effectively corrected.

Although various studies on misconceptions regarding thermochemistry have been conducted including those utilizing five-tier diagnostic tests the findings are generally context-specific and cannot be generalized across all learning environments. Each educational institution possesses unique student characteristics, learning environments, and teaching methods, which can give rise to distinct patterns of misconceptions. Furthermore, most prior research has focused primarily on identifying the extent of misconceptions, while information regarding their origins remains relatively limited. Consequently, there is a need for research that can specifically identify misconceptions within the context of individual schools while also tracing their underlying causes.

In line with this need, interviews with a chemistry teacher at SMAN 2 Siak Hulu revealed that many students continue to achieve poor learning outcomes in thermochemistry.

This is evidenced by an average daily test score of only 30, falling well short of the school's established Learning Objective Achievement Criteria (KKTP) of 85. Interestingly, while students tend to answer every question, a significant number of their responses are incorrect. This situation suggests that the issue stems not merely from a lack of knowledge, but potentially from unidentified misconceptions. If left unaddressed, this issue could hinder the understanding of subsequent chemistry topics and negatively impact assessment results and overall academic achievement.

Given these challenges, a more in-depth assessment of students' conceptual understanding of thermochemistry is required. Conventional evaluation tests typically measure only the correctness of answers, failing to clearly distinguish between students who lack conceptual understanding and those harboring specific misconceptions (Samaduri, 2022). Therefore, the use of a five-tier diagnostic test is considered more effective; it not only identifies students' answers and reasoning but also measures confidence levels in greater detail. This allows for a more accurate distinction between students who lack conceptual understanding and those harboring misconceptions, while also revealing the sources of information that shape students' understanding (Aprilia et al., 2026). Theoretically, the five-tier diagnostic test is an evolution of multi-tier diagnostic testing that integrates answers, reasoning, confidence levels, the validity of reasoning, and sources of information, thereby providing a more comprehensive picture of students' conceptual structures than three- or four-tier diagnostic tests.

The novelty of this study lies in the use of a five-tier diagnostic test to identify not only the level of misconceptions but also confidence levels and the sources of students' misconceptions regarding thermochemistry topics at SMAN 2 Siak Hulu. This study provides comprehensive information on misconception profiles tailored to the characteristics of students at the school; the results are expected to serve as a foundation for developing more targeted instructional and remedial strategies. The study aims to provide an overview of student misconceptions in thermochemistry to inform improvements in instruction. More broadly, it is expected to contribute to the field of chemistry education research, particularly regarding the identification of misconceptions using five-tier diagnostic tests. Based on this rationale, the study focuses on identifying misconceptions held by Grade XI students regarding thermochemistry using a five-tier diagnostic test at SMAN 2 Siak Hulu. The objective is to identify the level of student misconceptions for each thermochemistry concept and to uncover the sources of these misconceptions, thereby establishing a basis for designing more effective strategies to improve chemistry instruction.

METHODS

This study employs a descriptive research design with a quantitative approach. Descriptive research aims to describe a phenomenon as it exists in reality, without applying treatments or manipulating research variables (Tanjung & Albina, 2025). A quantitative approach is used to measure students' levels of misconception based on the results of a five-tier diagnostic test and to systematically describe the characteristics of the identified misconceptions (Zellatifanny & Mudjiyanto, 2018).

The study was conducted at SMAN 2 Siak Hulu during the even semester of the 2025/2026 academic year. The research population comprised all students from classes XI-4, XI-5, and XI-6 who had studied the topic of thermochemistry. The sample consisted of 100 students drawn from these three classes, all taught by the same teacher. A total sampling technique was used, meaning all population members meeting the criteria were included in the sample. Interview subjects were selected using purposive sampling based on specific criteria to ensure they could provide information supporting the findings regarding the identified misconceptions.

The primary research instrument was a 15-item five-tier diagnostic test adapted from (Islamiyah, 2025). The instrument covered seven thermochemistry concepts: heat and energy, systems and surroundings, exothermic and endothermic reactions, enthalpy changes, thermochemical equations, Hess's Law, and bond energy. The five-tier diagnostic test consists of five components: the multiple-choice answer, the confidence level regarding the answer, the reasoning for the answer, the confidence level regarding the reasoning, and the source of information upon which the student based their answer. This instrument was selected because it is capable of identifying both the level of conceptual understanding and the sources of students' misconceptions.

In addition to the test, the study utilized structured interviews as a supporting instrument to gather information on the causes of the misconceptions identified in the diagnostic test results. Interviews were conducted with students selected purposively based on their test result categories.

The test data were analyzed using descriptive quantitative methods. The analysis began with scoring the students' answers, followed by an analysis of confidence levels using the Certainty of Response Index (CRI). Subsequently, student responses were classified based on the combinations of the five-tier diagnostic test levels to identify categories of conceptual understanding and misconceptions, along with their underlying causes. Misconception percentages were calculated and grouped into three categories: low (0–30%), medium (31–60%), and high (61–100%). Interview data were analyzed descriptively through stages involving data reduction, categorization based on misconception sources, data presentation, and conclusion drawing to support the diagnostic test results.

The research was conducted in three stages. The first stage was preparation, comprising preliminary observation, teacher interviews, formulation of the research problem, development of research instruments, and consultation regarding the instruments with the academic supervisor. The second stage involved the actual research implementation: administering the five-tier diagnostic test to the entire sample and conducting interviews with selected students. The final stage was completion, which entailed identifying student answers, processing test and interview data, calculating misconception percentages, interpreting research findings, and compiling the research report.

RESULTS

1. Student Misconceptions

The identification results were then used to calculate the percentage for each conceptual category, as shown in Table 1.

Table 1. Percentages of Student Understanding Categories regarding Thermochemistry Material

Understanding Category	Average Percentage (%)
Understands Concept	27
Does Not Understand Concept	42
Misconception	18
False Positive	7
False Negative	6
Total	100

Based on Table 1, the category of student understanding regarding thermochemistry is dominated by the "lack of conceptual understanding" category, with an average of 42%.

This is followed by the "conceptual understanding" category at 27% and the "misconception" category at 18%. Additionally, "false positive" and "false negative" categories were identified at 7% and 6%, respectively. These findings indicate that the majority of students do not yet possess an adequate conceptual understanding of thermochemistry. Although the percentage of misconceptions is lower than that of the "lack of conceptual understanding" category, misconceptions were still observed among some students. Furthermore, the presence of students falling into the "false positive" and "false negative" categories indicates a discrepancy between their provided answers and their actual level of conceptual understanding.

2. Classification of Student Misconceptions by Thermochemistry Sub-topic

The study identified student misconceptions regarding thermochemistry using a five-tier diagnostic test instrument comprising 15 questions. The researchers analyzed the percentage of student misconceptions for each question; the results of this analysis are presented in Table 2.

Table 2. Percentage of Student Misconceptions by Sub-topic

No.	Thermochemistry Sub-topic	Average Misconception (%)	Category
1	System and Surroundings	16	Low
2	Heat and Energi	9	Low
3	Exothermic and Endothermic Reactions	19	Low
4	Thermochemical Equations	23	Low
5	Energy Level Diagrams	22	Low
6	Standard Reaction Enthalpy Change	18	Low
7	Determination of Reaction Enthalpy Change	18	Low
Average		18	Low

Based on Table 2, the percentage of student misconceptions across the various thermochemistry sub-topics shows variation. The average rate of student misconceptions across all thermochemistry sub-topics is 18%, falling into the low category. The sub-topic with the highest percentage of misconceptions is thermochemical equations (23%), followed by energy level diagrams (22%). The high level of misconceptions in these two sub-topics indicates that students still struggle to grasp concepts involving simultaneous symbolic and visual representations.

3. Sources of Student Misconceptions Based on Test Results

Based on the analysis of student answers, the sources of student misconceptions were categorized as shown in Table 3 below.

Table 3. Percentages of Sources of Student Misconceptions

No.	Source of Misconception	Percentage (%)
1	Personal Thinking	82.13
2	Teacher	6.19
3	Books	5.60
4	Friends	4.31
5	Internet	1.77
Total		100

Based on Table 3, the primary source of student misconceptions regarding thermochemistry is personal reasoning, accounting for 82.13%. Meanwhile, sources of misconceptions stemming from teachers, textbooks, peers, and the internet represent relatively small percentages: 6.19%, 5.60%, 4.31%, and 1.77%, respectively. These results indicate that the majority of misconceptions experienced by students arise from their own understanding or reasoning rather than from other learning sources.

DISCUSSION

The research results indicate that students exhibited misconceptions across all thermochemistry concepts assessed using a five-tier diagnostic test. The average misconception rate was 18% classified as low while the most dominant category was a lack of conceptual understanding. These findings suggest that the majority of students have not yet developed a complete conceptual understanding of thermochemistry. This state is preferable to holding misconceptions; students who simply lack understanding still have the opportunity to construct correct scientific concepts through appropriate instruction. In contrast, students harboring misconceptions hold firm beliefs in incorrect concepts, making them more difficult to rectify (Setyo et al., 2026).

Regarding specific sub-topics, thermochemical equations showed the highest rate of misconceptions (23%), followed by energy level diagrams (22%) and exothermic–endothermic reactions (19%). Conversely, the concepts of heat and energy exhibited the lowest misconception rate at 9%. The high prevalence of misconceptions regarding thermochemical equations indicates that students struggle to grasp the relationships between reaction coefficients, reaction direction, and enthalpy change (ΔH). Students tend to memorize rules for manipulating thermochemical equations without understanding the underlying conceptual connections, leading to errors when determining changes in the ΔH sign or modifying reaction equations. These results align with studies by Yanti et al., (2024), which found that learners struggle to modify thermochemical equations and determine changes in ΔH values.

Additionally, misconceptions were identified regarding the concepts of systems and surroundings, exothermic and endothermic reactions, energy level diagrams, standard reaction enthalpy changes, and the determination of reaction enthalpy changes. In general, students continue to struggle with linking abstract concepts to symbolic representations and mathematical calculations. These findings support the research of Rasyidah et al., (2024), which indicates that thermochemistry is one of the chemistry topics most prone to misconceptions because it demands both conceptual understanding and mathematical ability.

Conversely, the concepts of heat and energy showed the lowest rates of misconception. These results suggest that concepts linked to everyday experiences are easier for students to grasp than abstract ones. This finding aligns with the view of Mastuti, (2017), who stated that concepts close to real-life experiences tend to be more easily understood than those requiring symbolic and mathematical representations.

The study results reveal that the primary source of misconceptions is the students' own personal reasoning (82.13%), while other sources such as teachers, textbooks, peers, and the internet account for relatively small percentages. This finding indicates that most students construct their understanding based on prior knowledge and reasoning held before receiving accurate scientific explanations.

The dominance of personal reasoning as a source of misconceptions supports constructivist theory, which posits that knowledge is actively constructed based on an individual's learning experiences (Nerita et al., 2023). However, if this prior knowledge conflicts with scientific concepts, misconceptions form that are often difficult to alter. These findings also align with research by Bela & Mukarromah, (2026), which identifies prior knowledge as a major cause of misconceptions among learners.

Meanwhile, although their contribution is relatively small, textbooks, teachers, peers, and the internet can still serve as sources of misconceptions if the information received by students is not scientifically clarified. These results are consistent with studies by Andrini et al., (2026), which explain that factors such as the quality of learning resources, teacher instructional strategies, peer discussions, and low digital literacy can influence the formation of misconceptions.

The results of this study indicate that the five-tier diagnostic test is effective for distinguishing between students who hold misconceptions and those who simply lack conceptual understanding, while also identifying the sources of these misconceptions. Consequently, teachers can utilize this instrument for diagnostic evaluation both before and after instruction to tailor teaching strategies to students' needs. Teachers should also implement instructional approaches that emphasize cognitive conflict, conceptual discussion, and the use of various chemical representations to help transform erroneous concepts into scientifically accurate ones.

This study has limitations as it was conducted at a single school focusing solely on the topic of thermochemistry; consequently, the findings cannot be generalized to a broader population. Furthermore, the sources of misconceptions were identified based on answer choices at the fifth tier and supported by interviews with a subset of students. Therefore, future research could involve a larger sample and extend the study to other chemistry topics using five-tier diagnostic tests or other diagnostic methods.

CONCLUSION

This study reveals that Grade XI students at SMAN 2 Siak Hulu still harbor misconceptions regarding all the tested thermochemistry concepts, although the overall level of misconceptions falls into the low category. Furthermore, the most dominant source of these misconceptions stems from the students' own thinking, indicating that prior understanding and reasoning processes inconsistent with scientific concepts are the primary factors in the formation of misconceptions. Thus, the research objective to identify student misconceptions regarding thermochemistry and their underlying causes using a five-tier diagnostic test has been achieved.

The findings contribute to the development of chemistry instruction, particularly regarding the use of five-tier diagnostic tests as instruments capable of identifying not only students' levels of understanding and misconceptions but also the sources of those misconceptions. This information can serve as a basis for teachers to design more targeted instruction aimed at building students' conceptual understanding and minimizing the occurrence of misconceptions.

Future research is encouraged to apply the five-tier diagnostic test to other chemistry topics or in schools with different characteristics to obtain a broader overview of misconceptions. Additionally, it is recommended that teachers utilize the identified misconceptions as a foundation for designing instructional strategies capable of transforming students' initial concepts into scientifically accurate ones.

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