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Identification of Students' Misconceptions and Understanding on Thermochemistry Material with Four-Tier Multiple-Choice Tests

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Abstract. The delivery of chemistry learning lacking meaning and coherence is often associated with the occurrence of misconceptions. These misconceptions when not detected from the start, may persist and affect the understanding of subsequent materials. Therefore, this research aimed to identify misconceptions and understanding of concepts among students, with a focus on factors causing misconceptions about thermochemical materials. A quantitative descriptive approach was used with the four-tier multiple-choice test and questionnaire instruments. The samples comprised students in class XI Science at SMA Kawung 1 Surabaya. The results showed a profile of misconceptions about thermochemical material consisting of system and environment sub-concepts, types of systems, endothermic and exothermic reactions, types of enthalpy, as well as changes in reaction enthalpy. About 15% of students understood the concept, 31% had misconceptions, and 54% did not understand. Factors that caused misconceptions included poor understanding of the material, media used, teachers or methods, and learning resources.
Keywords: Misconception, thermochemistry, four-tier multiple-choice test

Introduction

Chemistry is a scientific study that discusses matter in terms of its properties, the changes it undergoes, and the energy involved in these changes (Hidayanti, 2021). The many concepts in chemistry make the teaching lesson look complex and abstract. The many concepts in chemistry make the lessons taught look complicated and abstract. In addition, chemistry lessons are unique and specific, containing concepts and calculations that are confusing and difficult as the grade increases (Huda et al., 2023). In chemistry, concepts or representations are divided into macroscopic, submicroscopic, and symbolic (Wicaksono, 2022). The macroscopic aspect describes phenomena that occur and can be directly observed in everyday life, such as density and solubility. Submicroscopic is an aspect that describes the chemical characteristics that seem abstract, which is used to explain macroscopic phenomena (Imaduddin, 2018). The submicroscopic aspect represents matter based on its particulate properties, while the symbolic aspect consists of images, symbols, and mathematical relationships in chemical equations. These representations are interrelated to help students understand an abstract chemical lesson (Wicaksono, 2022).

Students experience difficulties studying chemistry because they cannot connect macroscopic, microscopic, and symbolic aspects (Nurhayati & Natasukma, 2019). This inability can also lead to misconceptions. Misconceptions are misunderstandings that occur when connecting one concept with another, between new and old concepts embedded in student's minds (Suprapto, 2020). Student's misconceptions occur in almost all concepts in chemistry, one of which is dominant in the thermochemistry lesson (Rokhim et al., 2023). Thermochemistry is a unique material that contains many challenging concepts for students to learn (Wren & Barbera, 2013; Zakiyah et al., 2020). Understanding misconceptions in thermochemistry is an important task because previous research mentions that 65% do not answer thermochemical concepts correctly while learning completeness is limited to 42%, besides that student knowledge in Indonesia on chemical materials is only at the symbolic level, not yet to the macroscopic and submicroscopic (Wang, 2007; Wiji & Mulyani, 2018; Zakiyah et al., 2020). Studying thermochemical misconceptions is essentials for teachers because this material is a prerequisite for other materials. In chemistry, if one chapter is delivered with misconceptions, it will trigger misconceptions in other chapters (Jusniar et al., 2020b). Studying misconceptions that occur in thermochemical materials is also helpful in mapping the extent to which teachers can convey learning to students. So, it is necessary to do a deeper level of analysis of the level of understanding of students on thermochemical material.

The method that can be used to identify misconceptions or student's level understandings that occur is to use a diagnostic test instrument (Fakhriyah & Masfuah, 2021). A diagnostic test is an assessment used to investigate and identify students' strengths and weaknesses in a particular subject (Shim et al., 2017; Zhao, 2013). One of the suitable diagnostic test instruments used to identify misconceptions is the four-tier multiple-choice diagnostic test. This instrument is a development of a three-level multiple-choice diagnostic test. In the three-tier diagnostic test, the level of confidence for answers and reasons are combined, resulting in less specific results, whereas in the four-tier diagnostic test, the level of confidence in answers that are answered separately (Nurulwati & Rahmadani, 2020). Four-tier multiple-choice test is designed to determine how strongly a student has mastered a concept through the level of confidence in answering questions. This test consists of four levels: answer choices, answer confidence level, reason choices, and reason confidence level (Anggrayni & Ermawati, 2019). After that, students are classified based on the categories of scientific concepts, misconceptions, and do not understand the concept (Istiyono et al., 2023). This diagnostic instrument can assist educators in accurately analyzing students' understanding of concepts, determining sub-materials that require particular emphasis, knowing the factors that cause misconceptions, and designing learning that can overcome or prevent misconceptions (Nur et al., 2023). Apart from that, the use of a four-tier diagnostic test can also be used to test students' level of confidence in giving correct and incorrect answers or reasons (Yang, 2022).

However, currently, no research uses a four-tier diagnostic test to detect misconceptions about thermochemical materials. Efforts to detect misconceptions in thermochemical material are limited to multiple choice, true and false, reasoning, and descriptive (Ahmadi et al., 2023; Laliyo et al., 2023). Apart from that, the multiple-tier multiple-choice tests are limited to two and three tier diagnostic tests. A two-tier diagnostic does not include the level of confidence in the answer or reasoning, so it is unknown whether the learner is sure of the answer or just guessing at it (Supatmi et al., 2019). Whenever three-tier multiple-choice can't differentiate confidence levels in students' answers and reasons (Zakiyah et al., 2020). Even though thermochemical material is a complex material because it requires an in-depth understanding of concepts and skill in calculations, so more efforts are needed to detect misconceptions to determine the specific profile of students' understanding of the material (Kurnia et al., 2022). Thus, the information obtained can be used as material for evaluating teacher learning in chemistry subjects, especially the topic of thermochemistry. Identifying misconceptions in thermochemistry can also be used as a preliminary study to determine students' understanding of related material (Üce & Ceyhan, 2019).

Based on this background, this study aims to identify students' misconceptions and conceptual understanding in thermochemistry lessons using a four-level multiple choice test. So that misconceptions can be detected and dealt with because misconceptions that are not reviewed can lead to misconceptions in the next lesson (Grace et al., 2022). In addition, research on the identification of misconceptions also has the potential to support research on developing teaching materials and media that can reduce misconceptions or appropriate learning to prevent misconceptions (Damsi & Suyanto, 2023; Yang, 2022).

Methods

The method used in this research is descriptive method to identify students' misconceptions and understanding of thermochemistry lessons. This type of research is quantitative because the values obtained are calculated and represented in the form of numbers (Creswell, 2016). This type of research was chosen because it is effectively used to identify patterns in data to answer research questions (Loeb et al., 2017).

The participants of this study were students of XI science class SMA Kawung 1 Surabaya. The sample selection was adjusted to the purposive sampling technique based on the heterogeneous abilities of each student and the considerations of the chemistry subject teacher. Data collection techniques in this study included using a four-tier multiple-choice diagnostic test which can be used to identify the level of students' understanding of each thermochemical sub-material (Damsi & Suyanto, 2023). Furthermore, a student questionnaire identifies the causes of misconceptions in students about thermochemistry lesson.

The research test instrument consisted of an objective test in which the form used was a four-tier multiple-choice diagnostic test. The first level contains multiple choice answers, the second level contains the confidence level of the answers chosen at the first level, the third level contains the reasons for the answers selected at the first level, and the fourth level contains the confidence level of the reasons for the third level (Anggrayni & Ermawati, 2019).

The questions used for the four-tier multiple-choice diagnostic test already represent every sub-concept contained in the thermochemical lesson. The distribution of sub-concepts used in this instrument is shown in Table 1.

Table 1. Classification of sub-concepts in thermochemistry

No	Subject Matter
1	System and environment
2	System types
3	Endothermic and exothermic reactions
4	Types of reaction enthalpies
5	Reaction Enthalpy Change

(Ayyildiz & Tarhan, 2012; Febriyanti et al., 2019)

Data analysis techniques in the form of students' understanding and misconceptions were carried out by analyzing each combination of answers. Each combination of answers is then classified in Table 2.

Table 2. Classification of four-tier multiple-choice diagnostic test assessment results

Tier-1	Tier-2	Tier-3	Tier-4	Category
True	High	True	High	Understand Concept
True	Low	True	Low	Not Understand Concept
True	High	True	Low	
True	Low	True	High	
True	Low	False	Low	
False	Low	True	Low	
False	Low	False	Low	
True	High	False	Low	
False	Low	True	Low	
True	Low	False	High	Misconception
True	High	False	High	
False	High	True	Low	
False	High	True	High	
False	High	False	Low	
False	Low	False	High	
False	High	False	High	

(Fariyani & Rusilowati, 2015; Gurel et al., 2015)

After that, the percentage of students who experience misconceptions is calculated by dividing the number of students who experience misconceptions by the total number of students.

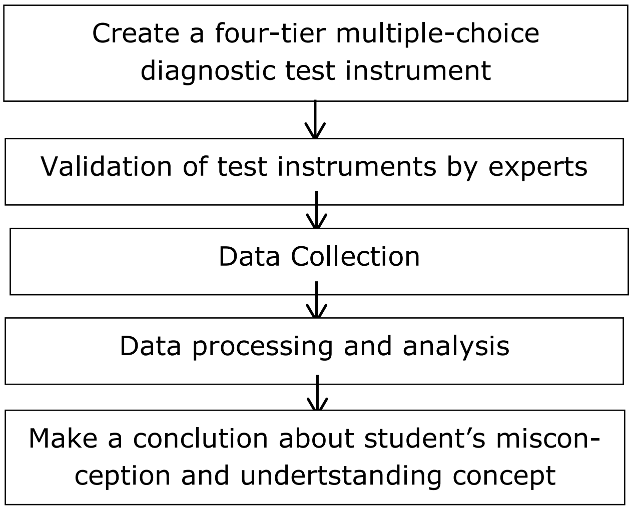

Figure 1. Stages of research

Results and Discussion

The analysis results are then grouped into three categories of student understanding: understanding concepts, misconceptions, and not understanding concepts. Overall, Students' understanding of thermochemical material can be seen in Figure 2.

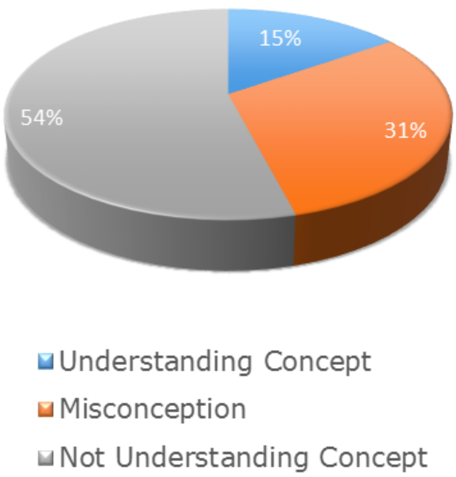

Figure 2. Percentage of students' understanding of thermochemistry lesson

Although fewer students Although fewer students experience misconceptions than those who do not understand the concept, only some students understand the concept of thermochemistry. This figure 2 shows that students' understanding of thermochemical material still needs to be improved. Then further research is needed to increase understanding and reduce students' misconceptions about thermochemistry lesson.

If categorized based on sub-concepts, the percentage of student understanding can be seen in Figure 3.

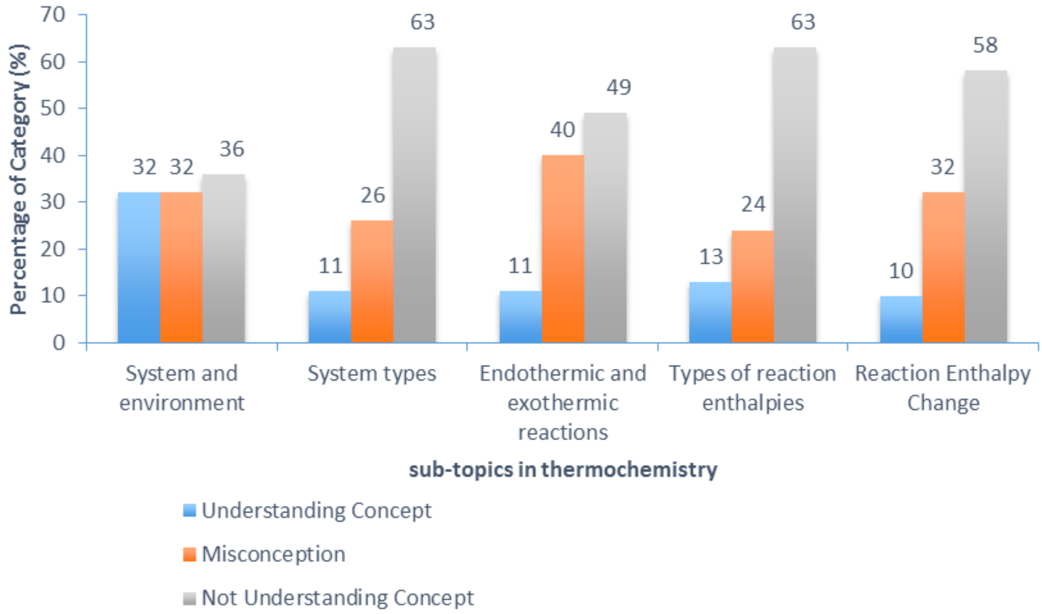

Figure 3. Percentage of students understanding in each sub-concept

In Figure 3, it appears that students experience a large percentage of misconceptions in each sub-concept. Details of student answers for each sub-concept are explained in the discussion below.

System and Environment Sub-Concept

In this sub-concept, students who experience misconceptions are the same as students who understand the concept. However, this percentage is less than students who do not understand the concept. Most misconceptions occur when students face several phenomena and are asked to classify systems and environments according to these phenomena.

Most students already know the meaning of system and environment. However, when faced with phenomena in the environment or laboratory, many students still have difficulty distinguishing between the two. Even though most students know the meaning of system and environment, these students still have low confidence, so many fall into the category of not knowing the concept.

When faced with reacting to two solutions, many students only choose one of the solutions or one of the final products as the system. In theory, all exchanges of energy and matter occur within the system (Smith & Konings, 2020). In this case, the system is the entire reacting solution because the center of attention is focused on the two solutions.

In this sub-topic, students who understand the theory but do not understand the application of the theory can experience misconceptions. So meaningful learning is needed, which involves more advanced organizers so that students can connect their pre-concept and new concept and truly understand the lesson (Kinasih & Sinaga, 2020). Meaningful learning can be presented by combining authentic experiments and complex metacognitive questions that help students interpret the data based on the material (States et al., 2023).

System Types Sub-Concept

In this sub-topic, the number of students who do not know the concept is more than half of the population. Even though the sub-concepts of system types are included in the easy category in thermochemistry material, this happens because some students still need help differentiating definitions and applying closed and isolated systems in everyday life. Several students assume closed and isolated systems are the same despite being different. a closed system as one that does not exchange any matter with its surroundings. In addition, an isolated system does not allow the transfer of energy either (Feireisl & Novotný, 2022).

Apart from that, most students' confidence level when answering questions or choosing reasons still needs to improve even though their answer is right. Based on that, it indicates that students need to fully understand sub-concepts of types of systems, especially when combined with phenomena in everyday life. If the confidence level is low, it also can indicate that the student answers the question by guessing, so the answer does not show the real student's knowledge about that sub-concept (Yang, 2022). It can also happen because the student does not understand the question clearly. The confidence level should be high when students understand the concept and truly know the answer (Yang, 2022). 36% of students experienced misconceptions about this sub-concept because when a phenomenon was presented, they could correctly describe the heat and material transfer. However, they still cannot classify the phenomenon into the correct type of system. For example, students can describe the transfer of matter and heat that occurs in LPG cylinder, but students think that LPG cylinder is a closed system, even though LPG cylinder is included in the isolated system category because can not transfer matter and energy (Feireisl & Novotný, 2022).

Endothermic and Exothermic Reactions Sub-Concept

In this sub-topic, the number of students who experience misconceptions and do not know the concept is almost the same. Some students were correct when giving examples of exothermic reactions. However, when asked to define them, they assumed that exothermic reactions absorbed energy from the system into the environment. The correct definition is that an exothermic reaction is a reaction that releases heat or energy from the system to the environment. Meanwhile, a reaction that absorbs energy is the endothermic reaction, which absorbs energy from the environment to the system (Petrucci et al., 2017).

The large number of students who need to learn the concept is also caused by choosing the wrong examples of exothermic reactions, even though they can correctly define the meaning of exothermic reactions. Many students still think that melting ice cubes and boiled water are exothermic systems, even though they are both endothermic systems because they absorb energy or heat from the environment. Apart from that, many students need to learn the concept because the confidence level in answering examples of exothermic and endothermic systems still needs to be higher.

Some students must still differentiate between sub-topics types of systems and endothermic or exothermic reactions. It was proven that when students were asked questions about types of reactions based on energy level diagrams, there were still those who chose open, closed, or isolated answers. Even though all three are types of systems and not reactions. Apart from that, most students also still incorrect reading energy level diagrams well, so they are confused or mistaken in choosing the type of reaction based on diagram. It can happen because students' high-order thinking skills (HOTS) are still low and need to be improved, so students can not analyse and interpret graphs clearly (Abdullah et al., 2021). It can also be due to students' weak symbolic representation skills, so they cannot interpret the symbolic realm in chemistry graphs (Upahi & Ramnarain, 2019).

Types of Reaction Enthalpies Sub-Concept

In this sub-topic, the percentage of students who do not know the concept is far from the other categories. It is because some students who are confident in their answers and reasons are correct when choosing the correct combustion reaction characteristics but still need to be corrected when answering the respiration process, including what type of enthalpy, so the answers and reasons do not match. Students also still need help categorizing the appropriate type of reaction enthalpy when several reaction equations are provided. Most students still need clarification on the reaction equations for standard enthalpy of decomposition and standard enthalpy of formation, so they are still difficult to differentiate the two.

Misconceptions in this sub-topic occur because students think that the respiration process that occurs in plants is the standard enthalpy of vaporization ($\Delta Hv°$), even though the respiration process is a type of standard combustion enthalpy ($\Delta Hc°$). It is because starch undergoes a combustion reaction (reacts with oxygen), forming carbon dioxide and water vapour (Nelson & Cox, 2017). In addition, most students assume that the enthalpy of decomposition always has a positive value ΔH. However, there is also a negative decomposition enthalpy, depending on the enthalpy changes that occur. This can happen because students simplify a concept, resulting in a false alternative understanding. Some students also consider the standard enthalpy of combustion to be the incomplete combustion of 1 mole of a substance. Even though the standard enthalpy of combustion is the complete combustion of 1 mole of a substance under standard conditions, students still cannot remember concepts well when presented with similar terms. It can happen because, in remembering a concept, students only rely on memorization and do not fully interpret it.

Reaction Enthalpy Change Sub-Concept

In this sub-topic, the number of students who understand the concept is only 10%. This percentage is the smallest percentage of all sub-topics. This sub-topic is divided into three sub-topics: determining reaction enthalpy using a calorimeter, reaction enthalpy from bond energy, and reaction enthalpy based on Hess's law.

When determining the enthalpy of neutralization using a calorimeter, misconceptions occur because students assume that the moles used to calculate enthalpy changes are moles of one of the reactants, even though the correct concept is that the moles used to calculate enthalpy changes are product moles. Meanwhile, students who do not know the concept because they cannot differentiate between exothermic and endothermic reactions in the question of determining the enthalpy of a reaction using a calorimeter, so some students are correct in answering the numbers but are wrong in choosing the positive (+) or negative (-) sign for the reaction enthalpy. Apart from that, many students still need to correct answers and reasons in this enthalpy calculation problem. It indicates that students' understanding is limited to the question formula, but when faced with questions involving calculations, students cannot solve them well. So, more emphasis is needed on practice questions, especially those involving calculations.

When determining reaction enthalpy from bond energy, misconceptions occur because some students assume that the ΔH is ∑product bond energy – ∑reactant bond energy, even though the correct concept is ΔH = ∑reactant bond energy – ∑product bond energy. This shows that students are still often confused in using the enthalpy change formula based on Hess's law or bond energy. This happens because students focus on remembering all similar concepts simultaneously, but only up to the remembering stage not real, so their memories are mixed between one concept and another.

One of the reasons for students needing to learn the concept is because of incorrect calculations. Students do not consider the number of bonds in the compound being reacted, whether single, double, or triple bonds. Some students assume that the bond in the compound must be single, so even though they know the correct formula, the answer can still be wrong. It shows that in chemistry, there must be a relationship between each concept, and when one concept is not studied properly, it can lead to errors in other concepts (Jusniar et al., 2020b). In addition, some students only calculate the enthalpy change in the bond energy of the main compound being reacted, so the answer still needs to be corrected.

Poor numeracy skills can also cause students to lack understanding of this subconcept. It causes students to have difficulty when faced with problems that require calculations, mathematical operations, and converting a problem into a form of mathematical operations. When student has a low numeracy skills, it can also impact to high order thinking skills (Suryanti et al., 2023).

When students are faced with an energy level diagram, there are still many students who cannot translate the energy level diagram well, so they make mistakes in calculating Hess's law. However, students already understand that ΔH of water evaporation equals the difference between $H_2O_{(l)}$ and $H_2O_{(g)}$. The discovery of students who still cannot interpret energy level diagrams but are familiar with the concept indicates that students need more learning using graphs, illustrations, and the like. Misconceptions also occur when students state that ΔH^o evaporation of water is the same for each mole. Even though at the reaction, the formula of $\Delta H^o = \frac{q}{mol}$ means that when the moles change, the ΔH^o value also changes (Petrucci et al., 2017).

Analysis causes of misconceptions and lack of understanding concept

After carrying out a four-tier diagnostic test to determine students' misconceptions and understanding, students were given a questionnaire to determine what influenced their understanding of thermochemical material. From this questionnaire, the percentage of factors that influence students' understanding can be seen in Figure 4.

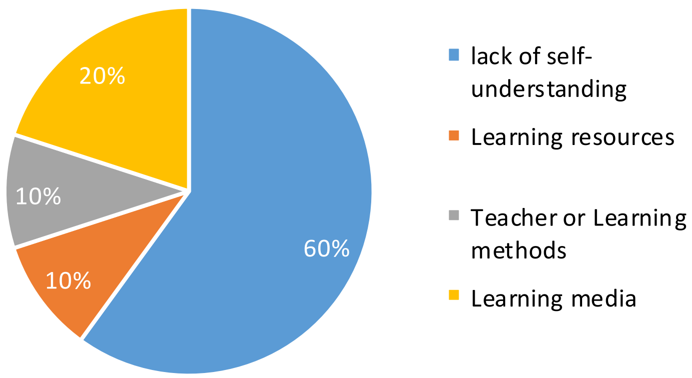

Figure 4. Factors that influence student's understanding in thermochemical material

The most significant factor that influences students' understanding is their poor understanding of the material. Students who learn something only by memorizing can only partially understand the material and quickly forget the content of the material (Putri et al., 2022). In addition, students' initial understanding or preconceptions that are different from the actual concept can influence their knowledge of the material to be studied, so students can make mistakes or not fully understand a concept (Jusniar et al., 2020a; Widarti et al., 2021). Students' poor understanding can also be caused by wrong learning methods and low motivation to learn chemistry (Lestari et al., 2021; Wahyuningtyas et al., 2020). The experiences in the daily lives of students who come from different backgrounds can also affect their understanding of the material.

The next factor that can influence students' understanding and misconceptions is learning media. Lack of engaging learning media can make students bored and uninterested in studying thermochemistry. Therefore, it is necessary to develop interactive and exciting learning media to increase students' understanding, such as flash-based interactive media, Android applications, websites, learning videos, games, virtual labs, and many more (Byusa et al., 2022; Fatah et al., 2021; Fatmawati et al., 2021; Harahap & Siregar, 2020; Harling, 2021; Lestari et al., 2023). Learning media can also unify students' conceptions (Rahma, 2019). Because with learning media, each student can have a different interpretation of the material. Besides that, learning media that deliver inappropriate learning content can lead to misconceptions. For example, the wrong animation or image and the noncoherent layout of the material can lead to different interpretations of the material.

Teacher or learning methods also influence students' understanding and misconceptions. Teachers still mostly use the lecture method when delivering thermochemical material. The lecture or teacher-centered method only requires students to memorize and record material so that students cannot fully understand it and have the potential for misconceptions Khairaty et al., 2018). The monotonous lecture method also makes students quickly bored and sleepy, so the learning material cannot be fully received because students ignore it (Haerunnisa et al., 2022; Mu'arikha & Qomariyah, 2020). So, learning methods must be student-centered so that students can construct their understanding more deeply through learning activities. Besides that, the teacher itself sometimes experiences misconceptions about his material. So, it is also important to identify and eliminate misconceptions among chemistry teachers or prospective teachers before presenting the material to students (Soeharto & Csapó, 2022). Misconceptions caused by teachers can occur because the teacher only relies on simple reading sources of thermochemical material, or chemistry teachers who teach do not come from a chemistry education background so that it can create a biased understanding of the material (Styawan & Arty, 2021).

Learning resources can also cause misconceptions in students. Currently, students can access materials from various sources, including the internet. Not all learning materials written on the internet are written by teachers or chemists, so there is great potential for the material to be wrong or inaccurate. The role of the teacher is to clarify the concepts that students get from various learning resources, whether the concept is correct or even incorrect. Teachers must also ensure that the books or worksheets to be used by students do not contain multiple interpretations or erroneous content.

Students also conveyed the chemistry learning methods they wanted to make it easier to understand the material. The student's general opinions are: 1) increase practice questions. It is because the thermochemical material involves many calculations and solving reaction equations, so it requires many practice questions. In completing practice questions, teachers can apply the peer tutoring method so that students understand the material more easily and are motivated to learn because the language conveyed by friends or peer tutors is easier to understand (Kurniawan et al., 2023; Merlin et al., 2023). 2) More practicum. Teachers can perform practicum demonstrations in front of the classroom, do practicum with students, or do practicum virtually. Apart from increasing students' understanding, practicum-based learning can improve students' science process skills and learning motivation (Jannah & Refelita, 2023; Setianingsih, 2023; Huda & Rohaeti, 2023). 3) Use of interesting and newest learning media. Teachers can create chemistry learning media based on games, comics, or augmented reality (Amirah & Mahartika, 2023; Kendek, 2023; Putri et al., 2023). Diverse learning media can increase students' motivation and interest in studying the material. 4) Using the student-centred learning model. Students can construct a complete understanding of the material when they actively learn. Studies using inquiry learning models can improve students' critical thinking skills, including evaluation, analysis, inference, interpretation, and essential clarification (Styawan & Arty, 2021).

Conclusion

Based on the research results on identifying misconceptions and students' understanding of thermochemical material using a four-tier multiple-choice diagnostic test, it was found that 54% did not understand the concept, 31% had misconceptions, and 15% understood the concept. It is indicated that students do not understand thermochemical material well. The causes of misconceptions among students include their lack of understanding, learning media, teachers or learning methods, and learning resources. Therefore, further efforts are needed to prevent or reduce students' misconceptions about thermochemical material.

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