

Original Article

Developing and Validating a Web-Based Five-Tier Diagnostic Instrument to Identify Student Misconceptions on Temperature and Heat

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Abstract: This study aims to develop and validate a web-based five-tier isomorphic diagnostic instrument to identify students' misconceptions on temperature and heat concepts in junior high school. This research employed a quantitative developmental approach, involving instrument development, construct validation, and descriptive analysis of students' responses. The instrument consisted of nine multiple-choice items structured into five tiers and was validated using factor analysis (Principal Component Analysis), with all items showing factor loadings greater than 0.50. Reliability testing using Cronbach's alpha yielded a coefficient of 0.745, indicating high internal consistency. A total of 101 eighth-grade students from SMP Negeri 12 Jambi participated in the study by completing the web-based diagnostic test. The results identified 13 types of misconceptions, with an average misconception rate of 12.56% across all tiers, indicating that although students' overall misconceptions were relatively low, several fundamental concepts related to temperature and heat remained problematic. The most common misconception was that dividing an object divides its temperature, accounting for 36.6%. Compared to conventional one-tier or two-tier diagnostic tests, this five-tier isomorphic instrument provides more detailed diagnostic information by incorporating students' reasoning and confidence levels. Therefore, this instrument contributes to science education research by providing a valid, reliable, and practical tool for diagnosing students' conceptual understanding and supporting more effective instructional planning in physics.

Keywords :

Temperature and Heat; Online diagnostic instrument; Student misconceptions; Five-tier diagnostic test; Isomorphic questions



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INTRODUCTION

A clear understanding of concepts is the basis for effective problem-solving. When students have concepts that do not correspond to scientific concepts but are confident in their understanding, it can be said that these students have misconceptions ([Fitriani et al.,](#)

2023; [Novianti et al., 2023](#); [Utami & Khotimah, 2023](#); [Maison et al., 2022](#); [Sandra et al., 2022](#)). A misconception is a concept that does not align with scientific understanding or the understanding accepted by experts in the field ([Maison et al., 2019](#); [Tarmizi et al., 2017](#); [Suparno, 2005](#)). Misconceptions experienced by students can be caused by internal factors (interest in learning, incorrect intuition, initial concepts, and insufficient mastery of concepts) and external factors (student and educator textbooks and the surrounding environment) ([Maison et al., 2025](#); [Rohman et al., 2023](#); [Andriani et al., 2021](#); [Fadllan, 2016](#)). If not identified and corrected early, such misconceptions persist and obstruct further conceptual development ([Sari & Oransa, 2025](#); [Qiu et al., 2025](#); [Yohanie et al., 2023](#); [Sari et al., 2023](#); [Chen et al., 2020](#); [Potvin & Cyr, 2017](#)). Misconceptions can occur in various fields, including physics, which is often considered a complex science and difficult to understand ([Astalini et al., 2019](#)).

Several studies have reported that misconceptions about temperature and heat are prevalent across educational levels. [Robo et al. \(2021\)](#) found that 47% of junior high school students and 54% of senior high school students exhibited misconceptions, while [Zayyinah et al. \(2018\)](#) reported that approximately 70% of junior high school students held misconceptions related to thermal concepts. Similarly, [Taqwa et al. \(2020\)](#) identified an average misconception rate of 51.44% among pre-service physics teachers, and [Maison et al. \(2019\)](#) found a misconception rate of 24.27% among senior high school students in Jambi. Taken together, these findings indicate that misconceptions about temperature and heat persist and occur consistently across educational contexts. However, most of this research uses paper-based diagnostic instruments with limited depth of analysis, which may not fully capture students' real conceptual understanding and is likely to result in fundamental misunderstandings. Therefore, a more comprehensive diagnostic approach is needed to accurately identify students' misconceptions ([Jannah, Ngaliah, & Anita, 2023](#); [Puri, Syefrinando, Reyza, & Taqwa, 2024](#)).

In recent decades, much educational research has focused on students' conceptions and how to diagnose and correct them ([Ansyah et al., 2021](#)). This line of research commonly uses misconception-diagnostic instruments to examine students' conceptual understanding in specific subject areas ([Laliyo et al., 2019](#)). Previous studies have widely used multi-tier diagnostic tests to identify students' misconceptions, including in physics topics such as light ([Maison et al., 2021](#)). However, existing diagnostic instruments, particularly four-tier tests, are still limited in their ability to examine the consistency of students' understanding across different representations of the same concept. One technique that can strengthen diagnostic analysis is the use of isomorphic instruments, which allow researchers to compare students' responses to parallel items measuring the same concept ([Triani et al., 2025](#); [Sutrisno et al., 2023](#)). Therefore, this study adopts a five-tier isomorphic diagnostic test, developed from a four-tier format by adding a fifth tier (Tier 5) that specifically evaluates the consistency of students' conceptual understanding without altering the core structure of the previous tiers. Unlike the earlier tiers, which focus on answers, reasoning, and confidence, Tier 5 serves as a meta-diagnostic layer that provides deeper insight into students' conceptual stability. This is consistent with previous findings that isomorphic tests can reveal students' understanding across multiple

representations and measure their ability to transfer knowledge between contexts ([Lamuda et al., 2024](#); [Muhasriady & Tiwari, 2024](#); [Ningsari et al., 2021](#)).

Based on classroom observations of junior high school students in Jambi City, a considerable number of students have not yet mastered the concepts of temperature and heat. This indicates that students' conceptual understanding of thermal concepts may be unstable and context-dependent, which cannot be fully captured by conventional assessment methods. However, research investigating students' explicit conceptual understanding of this topic, particularly using isomorphic five-tier diagnostic instruments, remains limited. The five-tier diagnostic test is designed to assess students' understanding of physics concepts and to provide more profound insights into the nature and sources of their misconceptions by examining answers, confidence levels, reasoning, and sources of information ([Bayuni et al., 2018](#); [Fatona et al., 2022](#); [Jumaera, Blessing, & Rukodo, 2024](#)). An isomorphic instrument uses several different questions to explore the same concept ([Fitriani et al., 2023](#)), in which a question is considered isomorphic when its solution relies on the same underlying concept but is presented in different representations ([Muhasriady & Tiwari, 2024](#); [Maison et al., 2023](#)). Previous studies have shown that isomorphic tests can describe students' understanding across multiple modes of representation and measure their ability to transfer knowledge between contexts ([Lamuda, Ashmawi, & Sangadji, 2024](#); [Muhasriady & Tiwari, 2024](#); [Ningsari et al., 2021](#)). Therefore, the novelty of this study lies in integrating a five-level diagnostic structure with an isomorphic approach to overcome the limitations of existing diagnostic methods and to provide a more comprehensive framework for identifying persistent misunderstandings especially in the material regarding temperature and heat.

This research is important because understanding physics concepts is crucial, as it helps students connect knowledge, facilitates learning, and strengthens the relationships among these concepts ([Cai et al., 2020](#); [Banda & Nzabahimana, 2021](#); [Nabila Junita & Dev Prasad, 2024](#)). Temperature and heat are fundamental concepts in physics and are closely related to many phenomena encountered in everyday life, yet they are also among the topics in which students frequently experience conceptual difficulties. Using a web-based, isomorphic five-tier diagnostic instrument, this study enables the identification of students' misconceptions about temperature and heat in a more detailed and systematic manner than conventional assessments. The integration of multiple tiers allows teachers to examine not only students' answers but also their reasoning, confidence levels, and conceptual consistency across different representations. Consequently, identifying common errors through this method can help teachers formulate more effective instructional strategies and design learning activities better aligned with students' needs. Furthermore, the findings of this study make important contributions to curriculum development by providing empirical evidence of persistent misconceptions in thermal concepts and by supporting the mastery of essential scientific knowledge. Therefore, the present study plays a meaningful role in enhancing educational practices and advancing the field of physics education.

Despite the extensive use of one-, two-, and four-tier diagnostic instruments to identify students' misconceptions, most existing studies focus only on students' answers and reasoning, without adequately considering their confidence levels and consistency

across isomorphic representations. In addition, previous diagnostic instruments are generally paper-based and do not fully utilize digital platforms to support efficient large-scale assessment. Therefore, there is a need for a web-based five-tier isomorphic diagnostic instrument that provides more comprehensive and accurate information about students' conceptual understanding, particularly of temperature and heat concepts at the junior high school level. The purpose of this study is to develop and validate a web-based isomorphic five-tier diagnostic instrument and to explore students' conceptual understanding of temperature and heat using isomorphic patterns.

METHOD

This study employed a descriptive quantitative approach to develop a five-tier isomorphic diagnostic instrument to identify students' misconceptions about temperature and heat. The participants were selected using purposive sampling, in which individuals are chosen based on predefined criteria relevant to the research objectives ([Ernawati et al., 2022](#); [Denieffe, 2020](#); [Maharani & Bernard, 2018](#); [Sugiyono, 2015](#)). The sample consisted of 101 eighth-grade students from SMP Negeri 12 Jambi who had previously studied temperature and heat. Data were collected using a web-based five-tier diagnostic test consisting of nine multiple-choice items. The five-tier structure included: (1) answer selection, (2) confidence level in the answer, (3) reasoning for the answer, (4) confidence level in the reasoning, and (5) sources of information used by students.

Construct validity was examined using exploratory factor analysis (EFA) with principal component analysis in SPSS. Factor extraction was based on eigenvalues greater than 1.0, and items with factor loadings below 0.40 were excluded from further analysis. The scree plot and rotated component matrix were used to determine the instrument's factor structure. The interpretation of construct validity followed the classification criteria presented in Table 1 ([Arikunto, 2014](#)).

Table 1. Validity Category

R	Validity interpretation
0.80 $<r_{xy} \leq 1.00$	Very high
0.60 $<r_{xy} \leq 0.80$	High
0.40 $<r_{xy} \leq 0.60$	Enough
0.20 $<r_{xy} \leq 0.40$	Low
0.00 $<r_{xy} \leq 0.20$	Very Low

Table 1 presents the criteria used to interpret the validity coefficient (r_{xy}) of the instrument items. The coefficient ranges from 0.00 to 1.00, where higher values indicate stronger validity. Items with coefficients between 0.80 and 1.00 are classified as having very high validity, reflecting a strong correlation with the measured construct. Coefficients between 0.60 and 0.80 indicate high validity, while values between 0.40 and 0.60 are considered moderate (or sufficient). Lower coefficients, ranging from 0.20 to 0.40, suggest low validity, and values between 0.00 and 0.20 indicate very low validity. This categorization helps determine the extent to which each item appropriately measures the

intended construct. Reliability was evaluated using Cronbach’s alpha, with coefficients above 0.70 considered acceptable for educational research ([Azizah & Chaimatusadiyah, 2025](#)). As for the indicators, the interpretation of the reliability coefficient following the classification is shown and referred to as in Table 2 ([Arikunto, 2014](#)).

Table 2. Interpretation of Reliability Values

Reliability value	Intepretation
0.80 $<r_{11} \leq 1.00$	Very high reliability
0.60 $<r_{11} \leq 0.80$	High reliability
0.40 $<r_{11} \leq 0.60$	Medium Reliability
0.20 $<r_{11} \leq 0.40$	Low Reliability
-1.00 $<r_{11} \leq 0.20$	Very low Reliability

Table 2 presents the criteria used to interpret the reliability coefficient (r_{11}) of the instrument. The coefficient ranges from -1.00 to 1.00 , with higher positive values indicating greater internal consistency. Reliability coefficients between 0.80 and 1.00 are classified as very high, reflecting excellent consistency among items. Values between 0.60 and 0.80 indicate high reliability, while coefficients between 0.40 and 0.60 represent moderate reliability. Lower coefficients, ranging from 0.20 to 0.40 , are considered low, and values below 0.20 indicate very low reliability. This classification assists in determining the consistency and stability of the instrument in measuring the intended construct. After the instrument was confirmed to be valid and reliable, it was administered to the participants to diagnose their conceptual understanding. Students’ conceptual understanding levels were categorized as low, medium, or high based on previously established criteria ([Sari et al., 2017](#)), as shown in Table 3.

Table 3. Conceptual understanding category

Description	Category
$0 \leq x \leq 30$	Low
$30 < x \leq 60$	Medium
$60 < x \leq 100$	High

Table 3 presents the classification of students’ conceptual understanding based on their test scores (x), expressed as percentages. Scores ranging from 0 to 30 are categorized as low, indicating limited understanding of the assessed concepts. Scores between 30 and 60 represent a medium level of understanding, reflecting partial comprehension with some remaining conceptual gaps. Meanwhile, scores above 60 up to 100 are classified as high, indicating a strong understanding of the concepts being measured. This categorization facilitates clearer interpretation of students’ performance levels.

RESULT AND DISCUSSION

Construct validity was examined using two complementary statistical approaches. First, exploratory factor analysis (EFA) using Principal Component Analysis (PCA) was conducted to evaluate the instrument's underlying factor structure and determine whether the items reflected the intended conceptual constructs. Factor extraction was based on eigenvalues greater than 1.00 , and items with factor loading values of at least $.40$ were

considered acceptable indicators of a construct. Sample adequacy was assessed using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett’s test of sphericity.

Second, item validity was evaluated using product–moment correlations to examine the relationship between each item and the total test score. An item was considered valid if its calculated correlation coefficient exceeded the critical value of the *r* table at the 0.05 significance level. The combined use of factor analysis and item–total correlations ensured both structural and empirical construct validity (Hair et al., 2021). Based on the calculations, the scree plot and *r* values for each questionnaire item are shown as follows:

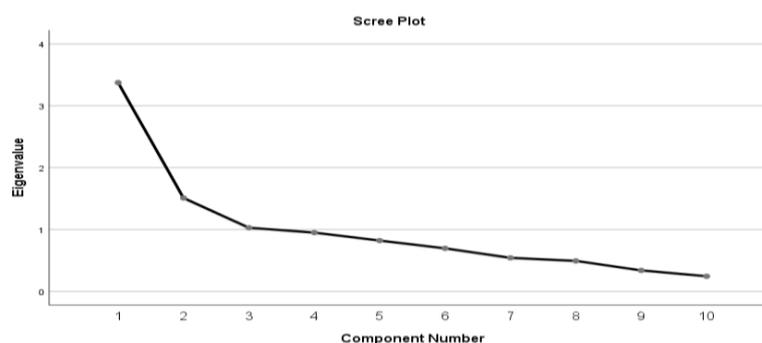


Figure 2. Scree Plot

The scree plot illustrates the distribution of eigenvalues across extracted components, with the x-axis showing component number and the y-axis showing the corresponding eigenvalue. The plot shows that three components have eigenvalues greater than 1.0, and a clear point of inflection (elbow) occurs after the third component, indicating that additional components contribute relatively little to explaining the variance. The retention of three factors is therefore statistically justified.

Conceptually, these three factors are meaningful because they correspond to the major dimensions measured by the five-tier diagnostic instrument, namely, students’ conceptual answers, reasoning processes, and confidence-related judgments. This suggests that the extracted components align with the instrument's intended structure and support its construct validity by clustering around theoretically relevant dimensions of students’ conceptual understanding.

Table 4. Validity of the construct of isomorphic instruments for temperature and heat

ITEM	Component		
	1	2	3
ITEM 1	0.627		
ITEM 2	0.566		
ITEM 3			0.967
ITEM 4		0.614	
ITEM 5		0.785	
ITEM 6		0.752	
ITEM 7	0.623		
ITEM 8	0.716		
ITEM 9	0.723		

The findings from the Rotated Component Matrix presented in Table 3 indicate the instrument's construct validity, as analyzed using Principal Component Analysis (PCA) with Varimax rotation. The analysis shows that Component 1 comprises Item 1, Item 2, Item 7, Item 8, and Item 9, each with factor loadings greater than 0.5, indicating that these items collectively represent students' core conceptual understanding of temperature and heat. Component 2 includes Items 4, 5, and 6, all of which exhibit factor loadings above 0.6, reflecting students' reasoning and explanatory aspects related to the concepts. In addition, Component 3 consists solely of Item 3, which has a factor loading of 0.967, indicating a very strong association with the measured construct. Although this component is represented by a single item, it was retained due to its theoretical relevance in capturing a distinct dimension of students' conceptual responses.

Furthermore, a reliability test was conducted on data from 101 students, yielding a Cronbach's Alpha of 0.745 (>0.60). This result indicates that the five-tier isomorphic diagnostic instrument demonstrates high internal consistency and reliability, making it suitable for use in educational research. Since the instrument has been empirically confirmed as both valid and reliable, it provides a sound methodological basis for analyzing students' conceptual understanding. Therefore, the results of implementing the developed website-based instrument are presented in Table 5, which shows the average percentage of students' correct responses after data analysis.

Table 5. Average percentage of correct scores for eighth-grade students at SMP N 12 Jambi

Misconception	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Mean
Only First Tiers	39,6%	37,6%	33,7%	61,4%	68,3%	42,6%	45,6%	45,5%	39,6%	40,9%
First & Third Tier	31,7%	26,7%	21,8%	56,4%	49,5%	33,7%	31,7%	32,7%	23,8%	34,2%
All Tier	30,7%	24,8%	21,8%	54,5%	47,5%	32,7%	31,7%	30,7%	22,8%	33%

Based on Table 5, the results show that eighth-grade students at SMP N 12 Jambi demonstrate varying average percentages of correct responses across different levels of understanding. The proportion of correct answers at Tier 1 is consistently higher than that at Tier 1 and 3 combined, as well as across all tiers. This occurs because Tier 1 evaluates only the selected answers without considering the underlying reasoning. In this respect, Tier 1 functions similarly to a conventional one-tier multiple-choice question. Students who answer correctly in tier 1 cannot be said to fully understand the concept, because there are two possible explanations behind correct answers. First, students answer correctly because they understand the concept. Second, students answer correctly either by guessing or by being right. Meanwhile, tiers 1 & 3 are two-tier questions in which, in addition to the answers, the reasons for choosing them are also considered, so the percentage is lower than in tier 1. Furthermore, for all tiers, not only are the answers and reasons taken into account, but also the confidence in both, so the percentage is even lower than the percentage for tier 1 alone and for tiers 1 & 3. This data is shown in the following graph.

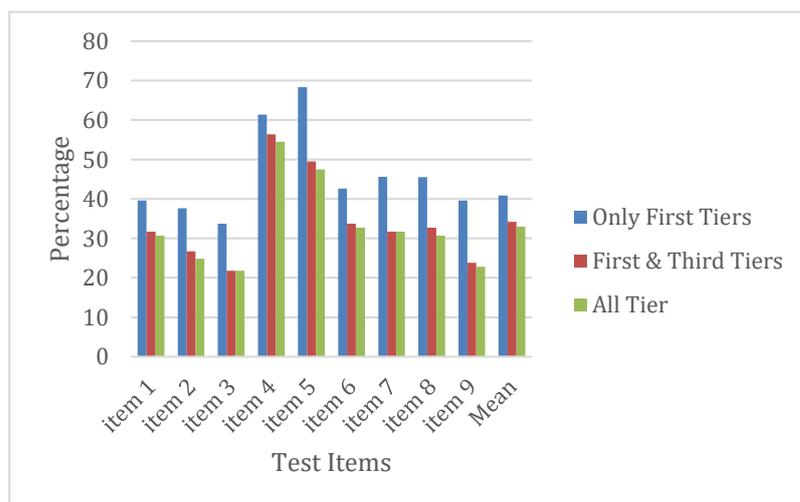


Figure 2. Average score graph for eighth-grade students at SMP N 12 Jambi

The mean percentage of correct responses at Tier 1 is 40.9%, decreasing to 34.2% when both Tier 1 and Tier 3 are considered, and further to 33% when all tiers are considered. The lowest average percentage is observed across all tiers because the evaluation considers not only students’ selected answers but also their reasoning and confidence in those choices.

Table 6. Percentage results of False Positives, False Negatives, and LK of students at SMPN 12 Jambi

	ITEM 1	ITEM 2	ITEM 3	ITEM 4	ITEM 5	ITEM 6	ITEM 7	ITEM 8	ITEM 9
Scientific Conception	30.69	24.75	21.78	54.46	47.52	32.67	31.68	30.69	22.77
False Positive	5.94	7.92	9.9	4.95	16.83	6.93	10.89	11.88	12.87
False Negative	4.95	6.93	4.95	19.8	1.98	24.75	16.83	28.71	21.78
Lack of Knowledge	2.97	8.91	9.9	4.95	5.94	10.89	11.88	9.9	8.91

Based on Table 6 above, the lowest percentage was observed for question 2 (24.75%), and the highest for question 4 (54.46%). For false positives, the lowest percentage was 6.93% in question 6, and the highest was 16.83% in question 5. For false negatives, the lowest percentage was 1.98% in question 5, and the highest was 28.71% in question 8. Furthermore, due to limited knowledge, the lowest percentage was in question 1 (2.97%), and the highest was in question 7 (11.88%). Students are considered to understand the concept when they provide the correct answer with high confidence and support it with a correct and scientifically appropriate reason. Students are categorized as *false positives* when they select the correct answer with high confidence but provide an incorrect reason, indicating superficial or partial understanding.

Students were categorized based on the accuracy of their answers and their confidence levels. Misconceptions were identified when incorrect responses were given with high confidence, false negatives when incorrect answers were paired with correct reasoning, lack of knowledge when incorrect responses were accompanied by low confidence, and guessing when correct responses were given with low confidence. Data were analyzed using a misconception classification table, with responses scored 1 if they matched a misconception category and 0 otherwise. Scoring was based on misconception types rather than simple correctness.

Table 7. Description of misconceptions of the topic: temperature and heat

Code	Misconception Description	Item Selection
M1	Metal objects tend to be cooler than their surroundings.	1.1 A 1.2 A 1.3 A 1.4 A 2.1 A 2.2 A 2.3 B 2.4 A
M2	Woolen items are warmer than their surroundings and retain heat.	1.1 B 1.2 A 1.3 B 1.4 A
M3	The temperature of objects inside the refrigerator can be lower than the temperature of the refrigerator compartment	1.1 D 1.2 A 1.3 D 1.4 A
M4	Metal objects are hotter than their surroundings.	2.1 C 2.2 A 2.3 A 2.4 A 2.1 D 2.2 A 2.3 A 2.4 A 3.1 D 3.2 A 3.3 C 3.4 A 3.1 E 3.2 A 3.3 C 3.4 A
M5	Objects that are continuously heated can reach temperatures higher than their heat source.	3.1 A 3.2 A 3.3 E 3.4 A
M6	Objects of different types will have different final temperatures even when in the same room.	3.1 C 3.2 A 3.3 C 3.4 A
M7	An object divided into several parts will have its temperature divided as well, so that each part has a lower temperature.	4.1 A 4.2 A 4.3 B 4.4 A 4.1 A 4.2 A 4.3 C 4.4 A 4.1 C 4.2 A 4.3 B 4.4 A 5.1 B 5.2 A 5.3 B 5.4 A 5.1 B 5.2 A 5.3 C 5.4 A 6.1 A 6.2 A 6.3 C 6.4 A 6.1 C 6.2 A 6.3 B 6.4 A
M8	The water temperature cannot exceed 100°C.	7.1 A 7.2 A 7.3 B 7.4 A 7.1 D 7.2 A 7.3 C 7.4 A
M9	At 100°C, water has absorbed all the heat energy, achieving temperature stability.	7.1 C 7.2 A 7.3 E 7.4 A
M10	The amount of heat is determined solely by temperature.	8.1 A 8.2 A 8.3 B 8.4 A
M 11	Temperature and mass can be interchanged, so that a small object with a high temperature and a large object with a low temperature will have the same amount of heat.	8.1 C 8.2 A 8.3 C 8.4 A
M12	Cold metal absorbs heat from water without changing temperature.	9.1 A 9.2 A 9.3 A 9.4 A 9.1 A 9.2 A 9.3 C 9.4 A
M13	Metals absorb heat, and water does not release heat.	9.1 B 9.2 A 9.3 D 9.4 A

The table above presents the categories of misconceptions along with the items used to assess each category. Following the scoring of Tier 1 (answers only), Tier 1 and Tier 3 (answers and reasoning), and all tiers (answers, confidence in answers, reasoning, and confidence in reasoning), the percentages of misconceptions among eighth-grade students at SMP Negeri 12 Jambi on the topic of temperature and heat were determined. The resulting distribution of students' misconceptions is presented as follows.

Table 8. Percentage of misconceptions among students

Misconception	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	M 11	M 12	M 13	Mean
Only First Tiers	51.4	10.8	4.9	51.4	14.8	31.6	67.3	40.5	11.8	43.5	10.8	29.7	30.69	30.71
First & Third Tiers	35.6	2.97	3.96	18.8	6.93	17.8	41.5	8.91	0.99	7.92	8.91	16.83	9.9	13.92
All Tier	35.64	2.97	3.96	15.8	5.94	15.8	36.6	7.92	0	6.93	6.93	15.84	8.91	12.56

Referring to the table above, the mean percentage of misconceptions at the first tier is higher than those observed at the subsequent tiers. This finding indicates that incorrect responses cannot be immediately classified as misconceptions, as such errors may also stem from students' limited knowledge. In general, the highest proportion of misconceptions is in the seventh category, whereas the lowest is in the ninth. The average percentages of misconceptions related to temperature and heat are 30.71% at Tier 1, 13.92% at Tier 1 and Tier 3 combined, and 12.52% across all tiers. These results indicate that, overall, students' misunderstandings regarding temperature and heat are still relatively low and still require improvement.

The findings of this study, conducted at SMP Negeri 12 Jambi using a website-based five-tier diagnostic test, indicate that the instrument is effective in identifying students' misconceptions about temperature and heat, as evidenced by satisfactory construct validity and reliability and consistent response patterns across the five tiers. The integration of answer accuracy, reasoning, and confidence levels enabled the instrument to distinguish between genuine understanding, misconceptions, and uncertainty.

The identification of 13 distinct types of misconceptions demonstrates that students' difficulties in temperature and heat are not limited to isolated errors but involve multiple conceptual dimensions. These findings highlight the diagnostic strength of the five-tier isomorphic format in revealing nuanced learning barriers that may not be detected by traditional multiple-choice or lower-tier instruments. Consequently, the results provide valuable information for teachers to design more targeted instructional interventions and to address specific conceptual weaknesses in thermal physics.

The data analysis indicates variation in the average percentage of correct responses across items. The highest proportion of correct answers across all tiers is found in Question 4 (54.5%), suggesting that the concept assessed in this item is relatively familiar to students and may involve more concrete or commonly encountered representations. In contrast, the lowest percentage of correct responses is observed in Question 3 (21.8%), indicating that

this item likely involves more abstract reasoning or conceptual integration, which poses greater cognitive difficulty for students.

Furthermore, the analysis of misconception data shows a decreasing trend across tiers. The average percentage of students' misconceptions is 30.7% at Tier 1, decreases to 13.9% when answer accuracy and reasoning (Tier 1 and Tier 3) are considered together, and further declines to 12.6% when all five tiers are integrated. This pattern indicates that including reasoning and confidence measures helps filter out superficial errors and distinguish genuine misconceptions from uncertain or guessed responses. Consequently, the five-tier structure provides a more refined and reliable diagnosis of students' conceptual understanding. The results showed that students still had misconceptions about temperature and heat.

The misconceptions that occurred among students at SMPN 12 Jambi on the topics of temperature and heat included:

M1 – Objects made of metal tend to have a lower temperature than their surroundings

This misconception was assessed using Questions 1 and 2, which asked students about the temperature of metal objects when touched. Based on the data, the percentage of misconceptions across all tiers was 35.64%, which falls into the *moderate category* according to the predetermined classification criteria. This indicates that a substantial proportion of students hold this misconception, although it is not dominant across the entire sample. Overall, students tended to assume that metals are cooler than their surroundings because they feel colder to the touch. Conceptually, however, the temperature of a metal object is the same as that of its environment after thermal equilibrium is reached. Metals feel cold because they conduct heat from the skin more rapidly than other materials, creating a stronger sensation of cooling. This finding highlights a common instructional challenge in physics: students' tendency to rely on sensory experiences rather than scientific reasoning. The five-tier structure was particularly useful for distinguishing between students who answered based on intuitive perception and those who demonstrated conceptual understanding, as the inclusion of reasoning and confidence levels revealed whether students' responses reflected stable misconceptions or merely reflected uncertainty.

M2 – Woolen items are warmer and retain heat

This misconception was measured by question no. 1. It arises from the belief that wool retains heat, thereby increasing its temperature. The percentage of misconceptions across all tiers was 2.97%, which is in the very low category. Students assume that wool is hotter than its surroundings because it retains heat. They do not yet understand that wool is a heat insulator that only slows the flow of heat from the body to the environment, rather than raising the object's temperature. Conceptually, wool is a heat insulator that slows down the transfer of heat from the body to the environment. However, this does not mean that wool generates or has a higher temperature. Its temperature eventually matches the ambient temperature.

M3 – The temperature of objects inside the refrigerator can be lower than the temperature of the refrigerator compartment

This misconception was measured using question no. 1, which tested students' understanding of the temperature of objects in a cold environment. Based on the data, the percentage of misconceptions across all tiers was 3.96%, which is classified as very low. Students thought that objects could become colder than the air inside a refrigerator, when in fact an object's temperature can only equal its environment's temperature after thermal equilibrium has been reached. Conceptually, an object's temperature will reach thermal equilibrium with its surroundings. Without an additional cooling mechanism, the temperature of an object cannot be lower than the temperature of the space in which it is located.

M4 – Objects made of metal have a higher temperature than their surroundings

This misconception was assessed using questions 2 and 3, which compared the temperatures of metals and other nearby objects. Based on the data, the percentage of misconceptions across all tiers was 15.8%, which is considered low. Students assume that metals are hotter because they feel hot when touched. They do not yet understand that the sensation of heat occurs because metals conduct heat more efficiently, not because they are hotter. Conceptually, metals conduct heat faster, so they can feel hot or cold depending on the temperature of the body or other objects that touch them. However, in thermal equilibrium, a metal and its environment have the same temperature.

M5 – Objects that are continuously heated can reach temperatures higher than their heat source

This misconception was measured using question no. 3, which tested the effect of continuous heating on an object's temperature. Based on the data, the percentage of misconceptions across all tiers was 5.94%, which is classified as very low. Students think that objects can become hotter than their heat source. They do not yet understand that heat transfer stops when the object's temperature equals that of the source, unless there are special conditions such as high pressure. Conceptually, an object cannot exceed the temperature of its heat source without an additional mechanism (such as pressure or reflection). Under normal conditions, the object's temperature approaches that of the heat source until it reaches equilibrium.

M6 – Objects of different types will have different final temperatures even though they are in the same room

This misconception was measured using questions that presented objects made of different materials in the same room. Based on the data, the percentage of misconceptions across all tiers was 15.8%, which is considered low. Students assumed that objects made of different materials would have different final temperatures even when in the same room. In physics, the final temperature will be the same because thermal equilibrium applies to all objects, regardless of their material type. The sensation of a temperature difference arises from differences in heat conductivity, not from actual temperature differences.

M7 – An object that is divided into several parts will cause its temperature to be divided as well, so that each part has a lower temperature

This misconception was measured using items 4, 5, and 6, which described the division of objects such as hot water or ice cubes. Based on the data, the percentage of misconceptions across all tiers was 36.6%, which falls into the moderate category. The M7 misconception had the highest percentage, namely the assumption that dividing an object into several parts will also divide its temperature. Students do not understand that temperature is an intensive quantity, which does not depend on mass or size. Dividing an object will not change its temperature; it will only reduce its mass and total heat.

M8 – The water temperature cannot exceed 100°C

This misconception was measured using item no. 7, which related to the boiling point of water. Based on the data, the percentage of misconceptions across all tiers was 7.92%, which is classified as very low. Students believed that water could not exceed 100°C. However, the views are the same and different, such as under certain conditions, such as high pressure, water can boil at temperatures above 100°C.

M9 – At a temperature of 100°C, water has absorbed all the heat energy, thus achieving temperature stability

This misconception was measured using item 7 on the boiling process. Based on the data, the percentage of misconceptions across all tiers was 0%, indicating that students generally understood this concept well. Most students understood that at 100°C, water that receives heat uses this energy to change state (evaporate) rather than increasing its temperature and this occurs consistently and continuously.

M10 – The amount of heat is determined solely by temperature

This misconception was measured using question 8, which asked about the relationship between temperature and heat. Based on the data, the percentage of misconceptions across all tiers was 6.93%, which is classified as very low. Students assumed that high temperatures always mean high heat. They did not understand that the amount of heat is influenced by three factors: mass, specific heat capacity, and the change in temperature.

M11 – Temperature and mass can be interchanged, so that a small object with a high temperature and a large object with a low temperature will have the same amount of heat

This misconception was measured using question no. 8, which compared two objects with different masses and temperatures. Based on the data, the percentage of misconceptions across all tiers was 6.93%, which is classified as very low. Students thought that a small object with a high temperature could have the same amount of heat as a large object with a low temperature simply because the values “balanced” each other out. They did not yet understand that $Q = m \times c \times \Delta T$ is a multiplicative relationship, not a substitution.

M12 – Cold metal absorbs heat from water without changing temperature

This misconception was measured using no. 9, which described metals in hot water. Based on the data, the percentage of misconceptions across all tiers was 15.84%, which is considered low. Students thought that metals could absorb heat without increasing in temperature. They did not understand that an object absorbs heat and, provided there is no change in state, its temperature increases.

M13 – Metals absorb heat, and water does not release heat

This misconception was measured using question no. 9, which involved heat transfer between water and metal. Based on the data, the percentage of misconceptions across all tiers was 8.91%, which is classified as very low. Students believed that only metals undergo energy changes, while water remains unchanged. In fact, in a closed system, the heat released by water equals the heat absorbed by the metal, in accordance with the law of conservation of energy.

Overall, the identified misconceptions reveal several cross-cutting conceptual patterns in students' understanding of temperature and heat. Misconceptions related to thermal equilibrium (M1, M3, M4, and M6) suggest that many students rely heavily on sensory experiences when interpreting temperature, leading to confusion between perceived and actual temperature. Misconceptions involving intensive and extensive quantities (M7, M10, and M11) pose greater conceptual difficulties, particularly in understanding that temperature does not depend on an object's size or mass. Among all categories, M7 had the highest percentage (36.6%), suggesting that this concept is the most significant learning obstacle.

In contrast, most misconceptions related to insulation, boiling, and heat conservation (M2, M5, M8–M13) were classified as very low, indicating relatively better conceptual understanding in these areas. The five-tier isomorphic structure played a crucial role in revealing these patterns, as integrating reasoning and confidence levels enabled the distinction between stable misconceptions and uncertain or guessed responses. These findings imply that instructional interventions should prioritize concepts of thermal equilibrium and intensive quantities, as these represent the most persistent and pedagogically significant barriers in students' learning of temperature and heat.

CONCLUSION

In conclusion, the web-based five-tier isomorphic diagnostic instrument developed in this study demonstrated satisfactory construct validity and high reliability, indicating its suitability for diagnosing students' conceptual understanding of heat and temperature. The findings revealed that students' understanding remains relatively low, with several persistent misconceptions identified. The most prominent misconceptions involved intensive and extensive quantities, particularly the belief that dividing an object reduces its temperature (M7), as well as misconceptions related to thermal equilibrium, where students relied on sensory perceptions rather than scientific reasoning. These results suggest that students face significant difficulties in distinguishing perceived temperature

from actual physical temperature and in grasping the fundamental nature of thermal quantities. By integrating answer accuracy, reasoning, and confidence levels, the five-tier isomorphic approach provides a more refined diagnostic tool than traditional methods, revealing not only whether students answer correctly but also the stability and sources of their misconceptions. Future research could extend this instrument to other physics topics or explore its integration into instructional interventions aimed at reducing misconceptions and enhancing conceptual understanding.

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