**Jurnal Ilmiah Pendidikan Fisika**
https://ppjp.ulm.ac.id/journals/index.php/jipf/index
e-ISSN: 2549-9963 p-ISSN: 2549-9955
Vol 9 No 1 2025
DOI:https://doi.org/10.20527/jipf.v9i1.14401

# Analysis of Item Difficulty and Student Misconceptions on Temperature and Heat Using a Two-Tier Diagnostic Test

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**Article Info**

**Article history:**
Received: February 2, 2025
Accepted: March 3, 2025
Published: March 29, 2025

**Keywords:**
Diagnostic test
Heat
Misconceptions
Temperature



**Abstract**

This study aimed to analyze the level of problem difficulty and students' misconceptions on the topic of temperature and heat using a two-tier diagnostic test. A two-tier diagnostic test was administered to a sample of undergraduate physics education students at three major universities in East Java to assess their understanding of these basic physics concepts. The first tier of the test evaluated students' ability to answer content-related questions correctly, while the second tier explored the reasoning behind their responses. Data were also collected on the Certainty Response Index (CRI) to determine students' confidence levels in their answers. Data analysis was conducted to determine the problem's difficulty level and identify common misconceptions. The results showed students had difficulty solving problems at levels C3 and C4, especially on representation problems. These findings highlight the need for appropriate teaching strategies to address these misconceptions and improve students' conceptual understanding of temperature and heat. This study provides valuable insights into assessing students' knowledge and identifying key areas for instructional improvement in thermodynamics teaching.

**To cite this article:** Royani, S.N.M., Artanti, K.P.A. I., Putri, R. A, & Parno, P. (2025). Analysis of item difficulty and student misconceptions on temperature and heat using a two-tier diagnostic test. *Jurnal Ilmiah Pendidikan Fisika*, 9(1), 144-.

## INTRODUCTION

Physics is a science that has many concepts to be able to understand and solve various problems related to the environment (Aji, 2017; Fatimah & Ulfa, 2022; Saparini et al., 2021). In studying physics, a deep understanding of concepts is very important so that students can apply this knowledge in various situations, both in everyday life and in scientific research. Improving the understanding of material science concepts among students has enormous importance in learning (Banda & Nzabahimana, 2021; Dewi & Ibrahim, 2019; Hau & Nuri, 2019). Conceptual understanding makes students connect what is already known and new physical phenomena (Banda & Nzabahimana, 2021). Knowledge of real-world physics concepts is an important component of physics learning that triggers students' innovative skills (Banda & Nzabahimana, 2021).

Misconceptions and various scientific concepts can happen to anyone. The most widely understood physics concepts are the concepts of temperature and heat (Saparini et al., 2021). Heat uses a physical and mathematical understanding (Eynde et al., 2023; Syahratinnur et al., 2023). Previous research stated that students have difficulty analyzing physical quantities in heat material (Laili et al., 2021). On the other hand, previous research stated that there were 42.86% misconceptions about temperature and heat material

(Saparini et al., 2021). Previous research also stated that temperature and heat material misconceptions are still quite high (Haryono & Aini, 2021). However, several efforts have been made by education activists, such as using graphic representations in temperature and heat material (Aprilia & Dwandaru, 2024), using PBL Model (Batlolona & Souisa, 2020), 7E model (Maskur et al., 2019), using digital game and computer simulation (Chaudhry et al., 2021), and physical, virtual, and hybrid laboratories (Tseng et al., 2023).

Studies consistently show that physics students and teachers still misunderstand heat and temperature. Studies have identified common misconceptions, such as the belief that cold can change or that air at 0°C is completely frozen (Musyarrofah, 2018; Yolanda et al., 2016). This misconception is common in a variety of concepts, including thermal expansion, phase changes, and heat transfer (Yolanda et al., 2016). To address this issue, researchers have explored remediation strategies. The use of Predict-Observe-Explain (POE)-based learning materials has shown promising results in reducing misconceptions and improving student understanding (Lebdiana & Hindarto, 2015). Other approaches include conceptual change strategies and problem-solving techniques (Sofianto & Irawati, 2020). Despite all efforts, misconceptions are still a major problem in physics education. This suggests that further research and development of useful teaching methods are needed to improve conceptual understanding and reduce misconceptions about temperature and heat. Therefore, an initial analysis of students' conceptual understanding of temperature and heat material is needed to find a learning model that is able to improve students' conceptual understanding abilities, especially in temperature and heat material.

One effort that can be made to identify student misconceptions is to use a two-tier diagnostic test (Laliyo et al., 2019; Soeharto & Csapó, 2022; Widiyatmoko & Shimizu, 2018). Through the use of two-tier diagnostic tests, researchers can find out the students' reasons behind the choices they have made. Research on the use of two-tier diagnostic tests has been conducted by Rakhmalinda et al. (2024) in analyzing students' misconceptions of acid-base material. Furthermore, research on identifying students' misconceptions using the two-tier test diagnostic test has also been conducted by (Nasir et al, 2023; Tukiyo et al, 2023; Yuliasari et al., 2023) whose research shows data on the large percentage of misconception identification experienced by students. A two-tier test study to identify misconceptions was also conducted by Ningroom et al. (2025).

## METHODS

This research is a type of non-experimental quantitative research. The research was conducted by distributing previously validated questions. The question distribution was carried out by distributing Google Drive online to 20 physics education students who had taken Basic Physics 1 and 2 courses at three state universities in East Java, namely Surabaya State University, Malang State University, and Jember University. Then, the answers were analyzed by calculating the level of difficulty using the following equation:

$$P = \frac{N_1}{N} \qquad (1)$$

Where P is the item difficulty level, $N_1$ is the total correct student answers, and N is the total number of students who answered the question. The results of the item difficulty level are determined using the Table 1 categories (Bano et al., 2022).

Table 1 Categorize by difficulty level

| Index | Criteria |
|---|---|
| $0 \leq P < 0.30$ | Difficult, poor test items, revised |
| $0.30 \leq P < 0.70$ | Moderate, good test items, used |
| $0.70 \leq P \leq 1.00$ | Easy, good test items, revised |

Of the 10 questions distributed, students' reasons for each will be analyzed individually to see the truth, errors, and disconnection between students' reasons and the answers given. This is used to identify the level of understanding of student concepts as the Table 2 modification of the understanding category from Majid et al. (2023).

Table 2 Category of first tier and second tier

| First Tier | Second Tier | Description |
|---|---|---|
| Correct | Correct | Understand the concept |
| | False | Misconception |
| | Unrelated | Don't know the concept |
| False | Correct | Understand the concept |
| | False | Misconception |
| | Unrelated | Don't know the concept |

The results of the answers will then also be analyzed how the level of student understanding in the C1 (remembering), C2 (understanding), C3 (application), and C4 (analysis) categories so that it is known how the level of student understanding in each category of questions (Sopian, 2021). In addition, the Certainty of Response Index (CRI) is also used on each item to see students' confidence in answering questions. The results of this CRI are then categorized based on the criteria in Table 3.

Table 3 Categorized CRI

| CRI | Criteria |
|---|---|
| 0 | Totally guessed answer |
| 1 | Almost guess |
| 2 | Not Sure |
| 3 | Sure |
| 4 | Almost Certain |
| 5 | Certain |

Table 4 Detailed categorized CRI

| Answer Criteria | Low CRI (CRI<2.5) | High CRI (CRI>2.5) |
|---|---|---|
| Correct Answer | Correct answer and low average CRI means not knowing the concept | A correct answer and a high average CRI means that the concept is mastered. |
| Wrong Answer | Wrong answer and low average CRI means do not know the concept | Incorrect answers and high average CRI mean misconceptions occur |

(Mujib, 2018)

## RESULTS AND DISCUSSION

The identification of each item's difficulty level was carried out by referring to the formula for the difficulty of the question by Ding and Beichner (2009) by comparing the number of correct answers with the number of students who answered the answer. Based on the results of student answers, then analyzed on Microsoft excel and obtained data as shown in Figure 1.

Based on Figure 1, it can be seen that of the 10 questions tested, there are three categories of questions that are included in the low level of difficulty (easy), four questions in the medium level, and three questions in the high level of difficulty. Based on the questions given, students do not have any problems completing questions C1 and C2, namely remembering and understanding. Students can remember the temperature measuring instrument used, the units, and how to understand temperature. However, students find it difficult to answer questions in categories C3 (applying) and C4 (analyzing). This means that students still have difficulty working on questions with a higher cognitive

level (Pratama et al., 2024). Question C3 is presented using a graphical representation of the relationship between temperature and the diameter of an object. Most students have difficulty understanding the meaning of the gradient of the graph presented. This shows a low graphical representation ability (Faradila et al., 2022). In question C4 (analyzing), students have difficulty analyzing problems presented in ratios or comparisons. This shows that there are still many students who have difficulty in completing questions in categories C3 and C4 (Yusuf & Widyaningsih, 2018). The two-tier question format was used in this study to identify the level of student understanding of each question item (Batlolona Souisa, 2020)

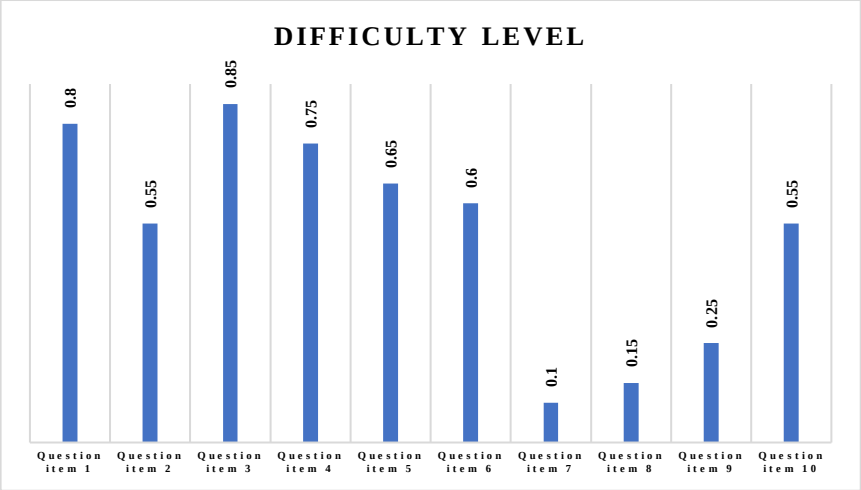


Figure 1 Level of difficulty

Table 5 briefly shows the level of understanding and representation of the number of students.

Table 5 The detailed students conceptual understanding of research

| Question | Correct Answer | Answer Criteria | Percentage | Description |
|---|---|---|---|---|
| 1 | 16 | Correct | 80% | Understand the Concept |
| | | False | 15% | Misconception |
| | | Unrelated | 5% | Do not understand the concept |
| 2 | 11 | Correct | 55% | Understand the Concept |
| | | False | 20% | Misconception |
| | | Unrelated | 25% | Do not understand the concept |
| 3 | 17 | Correct | 85% | Understand the concept |
| | | False | 7% | Misconception |
| | | Unrelated | 8% | Do not understand the concept |
| 4 | 15 | Correct | 75% | Understand the concept |
| | | False | 15% | Misconception |
| | | Unrelated | 10% | Do not understand the concept |
| 5 | 13 | Correct | 65% | Understand the concept |
| | | False | 22% | Misconception |
| | | Unrelated | 13% | Do not understand the concept |
| 6 | 12 | Correct | 60% | Understand the concept |
| | | False | 25% | Misconception |
| | | Unrelated | 15% | Do not understand the concept |
| 7 | 2 | Correct | 10% | Understand the concept |
| | | False | 50% | Misconception |

| Question | Correct Answer | Answer Criteria | Percentage | Description |
|---|---|---|---|---|
| | | Unrelated | 40% | Do not understand the concept |
| 8 | 3 | Correct | 15% | Understand the concept |
| | | False | 75% | Misconception |
| | | Unrelated | 10% | Do not understand the concept |
| 9 | 5 | Correct | 25% | Understand the concept |
| | | False | 60% | Misconception |
| | | Unrelated | 15% | Do not understand the concept |
| 10 | 11 | Correct | 55% | Understand the concept |
| | | False | 15% | Misconception |
| | | Unrelated | 30% | Do not understand the concept |

Based on Table 5, the results show that in the previous easy category questions (item 1, item 3, and item 4), many students answered correctly but still gave the wrong reason for choosing the answer. This shows the presence of student misconceptions about temperature and heat material (Asmin & Rosdianti, 2021). Likewise, in the category of difficult questions (items 7, 8, and 9), the number of students who experienced misconceptions was far higher than students who understood the concept and did not understand the concept. Students understanding the concept here can give correct reasons and relate to their chosen answers. Meanwhile, students who have misconceptions are students who answer correctly but give the wrong reasons. Finally, students who do not understand the concept answer correctly or answer incorrectly, but the reasons are unrelated to the problem. Table 5 can also be generalized by looking at the percentage of students who understand the concept, misconceptions, and do not understand the concept through the following chart.

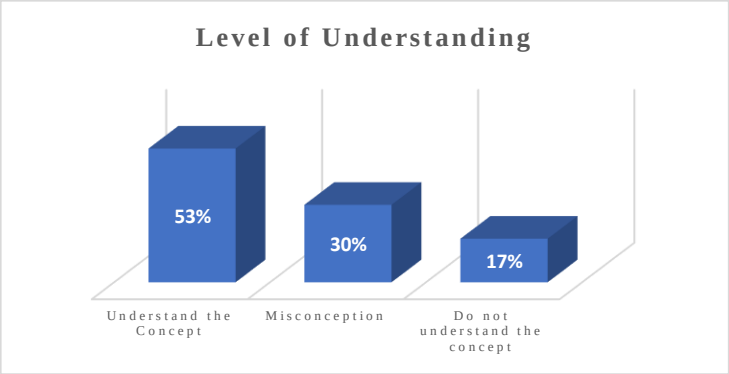


Figure 2 Level of understanding in general

The item with the largest percentage of concept understanding is item 1; this shows that many students understand that length expansion mainly occurs in solid objects, especially metals such as aluminum, iron, and copper. This choice shows a good understanding of the nature of expansion in metals and solids. Meanwhile, the item where most students made mistakes was item 7. This shows that students are less able to make in-depth analyses by considering how materials with lower expansion coefficients can be advantageous for maintaining glass stability, showing strong understanding and appropriate application skills.

After working on each item, the researcher also analyzed the students' confidence level in their answers. This was done using CRI on a scale of 1-5. The results of each student's CRI are given in Figure 3.

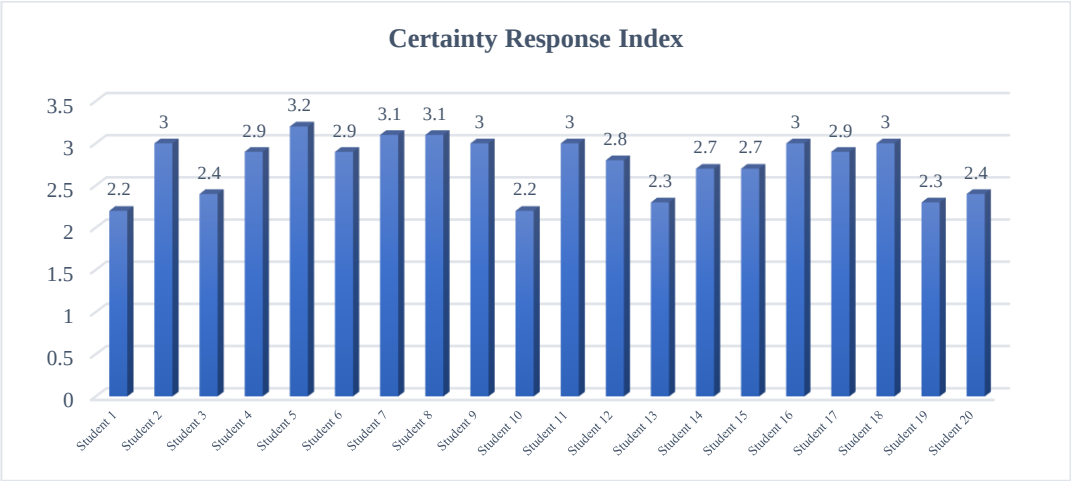


Figure 3 Certainty response index

Based on the table, the results show that 30% of students still have low self-confidence in the results of each question they have done. While the other 70% feel confident that their results are correct. By looking at the CRI percentage and the difficulty level of each question, it can be concluded that the ratio of the difficulty of the question item to the CRI is related. Three questions are considered difficult, and seven others are in the medium to easy category. CRI data showed that 70% of students were confident in their answers, and 30% were less confident. So, it can be concluded that the level of self-confidence and the difficulty of the question item may be considered related.

## CONCLUSION

Based on the analysis of two-tier diagnostic test questions on temperature and heat material, it was found that there were 3 questions in the easy category, 4 questions in the medium category, and 3 questions in the difficult category. In addition, the reasons given by students and the answers chosen were also analyzed to see the level of student understanding. The results showed that in questions with low difficulty levels, many students understood the concept by giving correct reasons, while in difficult items, many students gave incorrect reasons and did not even relate to the answer. Not only that, but this study also provides data on students' confidence in their answers. The results showed that students' confidence was high at 70%. This research is still limited to 20 subjects from 3 large campuses in East Java; it is also limited to question levels C1 to C4, so it is hoped that further research can expand the subjects and question levels.

## CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

## AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, SNMR; methodology, KPAIA; data collection, KPAIA; formal analysis, SNMR, RAP; writing original draft preparation, SNMR; writing review and editing, P; supervision, P.

## ACKNOWLEDGMENTS

The authors would like to express their gratitude to Universitas Negeri Malang for providing academic support and facilities that contributed to the completion of this research.

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