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Unveiling Heat and Temperature Misconceptions: A Multilocation Study on First-Year College Students in Indonesia

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Abstract

This study aims to identify misconceptions experienced by first-year university students regarding the concepts of temperature and heat. This research applied a descriptive research design. The sample consisted of 224 first-year students from public and private universities in Singkawang, Bima, Madiun, and the Sumedang, Sintang, and Bandung regencies. The instruments used were adopted from two previous studies and validated by experts. The test reliability results were 0.73 and 0.75, indicating a high level of reliability. Data were collected via Google Forms, using questionnaires and a four-tier test as the instruments. The findings indicated that the highest percentage of misconceptions among students occurred in the sub-topic "Temperature will continue to rise as long as the fire remains on while boiling water," with 63% of students displaying this misconception. The lowest misconception occurred in the sub-topic "Water at 0°C has entirely turned into ice," with 40.6% of students holding this misconception. It is hoped that these findings can be utilized by lecturers and teachers to address the sub-topics of temperature and heat, which are known to harbor numerous potential misconceptions. Consequently, lecturers can employ effective teaching strategies to address students' misunderstandings regarding temperature and heat.

Keywords: four-tier test; heat and temperature; misconception

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INTRODUCTION

In recent years, students' understanding of scientific phenomena has garnered increasing attention from science education researchers. Scholars agree that students bring their pre-existing concepts and ideas into the classroom, shaping their thinking. However, these ideas do not always align with scientists' ideas (Garba, 2015; Mubarokah et al., 2018). Students whose concepts align with scientific principles are more likely to strengthen their understanding, whereas those with misconceptions may resist new scientific information and need help integrating it into their existing frameworks (Foroushani, 2019; Yildirim et al., 2021).

One critical factor in physics pedagogy is addressing misconceptions among prospective teacher candidates (Bani-salameh, 2018; Halim et al., 2020). Prospective teacher candidates must first grasp the fundamental concepts to teach physics effectively. If these candidates need clarification, the students they teach will likely develop similar understandings (Hermita et al., 2018; Yuliana et al., 2020). Misconceptions among prospective teachers may arise due to the abstract nature of the concepts they are learning (Sukarelawan et al., 2019). As a result, prospective teachers who perform poorly in physics often need help comprehending the basic concepts presented by their instructors, indicating a lack of solid conceptual understanding. This gap in understanding stems either from misinterpretation of the concepts or incomplete comprehension (Akcanca & Cerrah Özsevgeç, 2020; Gerhátová et al., 2021; Rosdiana & Kholiq, 2021). Such misunderstandings are further compounded by students' difficulty grasping abstract material. The more prevalent the misconceptions, the more challenging it becomes to correct them, particularly in the context of physics education (Temel & Şen, 2019). Identifying and addressing these misconceptions is essential, as they can significantly hinder the learning process and impact students' conceptual development.

Misconceptions in physics are prevalent across various topics, including temperature and heat (Gürses et al., 2022; Santhalia et al., 2020; Temel & Şen, 2019); electrical circuits (Halim et al., 2019) impulse and momentum (Samsudin et al., 2015; Triyani et al., 2019); fluids (Halim et al., 2020; Saputra et al., 2023); as well as power and energy (Andriyani Saputri, 2021; Liu & Fang, 2017). However, the most widespread misconceptions tend to occur in the concepts of temperature and heat (Gürses et al., 2022; Irsyad et al., 2018; Linuwih et al., 2022; Mujib, 2020; Temel & Şen, 2019). To address these misconceptions, tools for their identification are necessary. Diagnostic tests have proven to be particularly effective among the various tools available. These tests offer a highly efficient means of identifying misconceptions, enabling researchers to detect student misunderstandings more quickly than other methods. Moreover, substantial data have been collected on university students' errors and misunderstandings as identified through diagnostic tests.

The diagnostic assessment employed in this study is structured as Multiple Choice Tests (MCT), which can be utilized in various ways. MCTs assess students' understanding and help specifically identify those who harbor misconceptions (Kanwal & Farooq, 2021; Maison; et al., 2019). This enables lecturers to identify patterns of misconceptions and provide targeted interventions for each individual (Ali, 2011; Bani-salameh, 2018). There are different types of MCTs, including two-tier MCTs (Appiah-twumasi, 2021; Trudel, Louis; Métioui, 2021); three-tier MCTs (Haryono et al., 2021; Suliyanah et al., 2018) and four-tier MCTs (Budi Bhakti et al., 2022; Muchamad et al., 2019). While two- and three-tier MCTs can identify misconceptions, they have notable limitations. Two-tier MCTs are more likely to uncover student misconceptions but do not provide insight into the students' confidence in their answers (Trudel, Louis; Métioui, 2021). Additionally, the commonly used three-tier MCTs, while assessing student confidence at the first level, fail to reveal the students' confidence in their chosen reasoning at the third level (Akcanca & Cerrah Özsevgeç, 2020; Haryono et al., 2021). This limitation leads to two main issues: failing to account for ignorance and identifying students who may be guessing. Meanwhile, four-tier MCTs address the limitations of two-tier and three-tier MCTs. Four-tier MCTs offer several advantages, including enhancing students' conceptual understanding by instilling confidence in the rationale behind their choices. They also provide greater specificity in identifying student misconceptions as a valuable tool for assessing students' deeper understanding. Additionally, they help lecturers determine appropriate teaching strategies to address and reduce misconceptions in the classroom (Maison; et al., 2019).

In this study, the researchers aim to identify misconceptions among prospective teacher candidates about temperature and heat using a four-tier diagnostic test. This research aims to offer a reference for lecturers and academics in identifying the key misconceptions related to the concepts of temperature and heat.

METHOD

This study aimed to identify misconceptions among first-year prospective teacher candidates regarding the concepts of temperature and heat. The research employed a descriptive study approach to understand the misconceptions held by first-year prospective teacher candidates concerning the concepts of temperature and heat. The instruments used included a questionnaire and a four-tier test. The four-tier test was adopted from the research of Asri Devialita and Endah Nur Syamsiah. The instrument developed by Asri Devialita had been tested for validity by experts, with an average CVR value of 1, indicating that the instrument was valid. Additionally, the reliability result was 0.73. The instrument developed by Endah Nur Syamsiah had also been tested for validity by experts and was declared valid, with a reliability level of 0.75. The study was conducted from March 2023 to April 2023, using a Google Form distributed to several public and private universities in Singkawang, Bima, Madiun, Sumedang Regency, Sintang Regency, and Bandung Regency. A sample of 224 first-year students participated in the study. The sampling method used was random sampling. By randomly selecting samples, the researchers ensured that various types of misconceptions that might exist among students were represented in the sample.

The instrument used in this study was the four-tier test. This test was employed to investigate the misconceptions that existed among students. The test was distributed via Google Forms to several universities. The four-tier test consisted of four levels. The first level included multiple-choice questions with four response options. The second level indicated the respondents' confidence in their selected answers. The third level involved justifications for the responses. The fourth level assessed the respondents' confidence in the reasons they provided. The distribution of respondents' misconceptions was analysed based on the answer decision categories. This decision was grounded in the scientific argument that students who misunderstood a concept, whether in part or as a whole, were still considered to have misconceptions. The results of the four-tier test decisions were adapted from (Muliyani & Kurniawan, 2021) and are presented in Table 1.

Table 1 Four-tier test decision

***Tier*-1**	***Tier*-2**	***Tier*-3**	***Tier*-4**	**Decision**
True	Sure	True	Sure	Scientific Conception
True	Not Sure	True	Not Sure	Lucky guess
Wrong	Not Sure	True	Not Sure	Guess
True	Not Sure	Wrong	Not Sure	Guess
Wrong	Not Sure	True	Sure	Guess

***Tier*-1**	***Tier*-2**	***Tier*-3**	***Tier*-4**	**Decision**
True	Not Sure	True	Not Sure	Lack of Knowledge
True	Not Sure	True	Sure	Lack of Knowledge
True	Not Sure	Wrong	Not Sure	Lack of Knowledge
Wrong	Not Sure	Wrong	Not Sure	No Understanding
Wrong	Sure	True	Sure	Misconception
Wrong	Sure	True	Not Sure	Misconception
Wrong	Sure	Wrong	Sure	Misconception
Wrong	Sure	Wrong	Not Sure	Misconception
Wrong	Not Sure	Wrong	Sure	Misconception
True	Sure	Wrong	Sure	Misconception
True	Not Sure	Wrong	Sure	Misconception

RESULTS AND DISCUSSION

The four-tier test revealed the extent of the students' misconceptions about the concepts of temperature and heat. The misconceptions encountered by the students were analyzed according to the classification in Table 1. The data collected consisted of responses from 224 first-year prospective teacher candidates regarding temperature and heat. Table 2 illustrates the number of prospective teacher candidates who encountered misconceptions about temperature and heat concepts.

Table 2 The number of students experiencing misconceptions on the concepts of temperature and heat

No.	**Misconceptions**	**Student Percentage (%)**
1	An object that feels chilly to the touch must possess a lower temperature than an object that feels warm when touched.	58.5
2	An object with a higher temperature surely contains more heat than an object with a lower temperature.	62.1
3	When heated, an object that readily increases in temperature will be more challenging to cool down.	47.3
4	Water at a temperature of 0°C has completely turned into ice.	40.6
5	The temperature rises as long as the fire keeps burning while boiling.	63.0
6	The thickness and thinness of an object affect the amount of heat absorbed.	54.0
7	When two objects are heated evenly, the object's temperature with a larger mass increases more.	54.4
8	When exposed to sunlight, the ocean and the sand on the beach have the same temperature.	45.5

Table 2 indicated that students continued to harbor misconceptions regarding the concepts of temperature and heat, albeit with varying percentages of affected individuals. The highest percentage of misconceptions was found in the sub-topic "The temperature will continue to rise as long as the fire keeps burning while boiling," with 63% of students holding this misconception. The lowest percentage of misconceptions occurred in the sub-topic "Water, when it is at a temperature of 0°C, has become ice as a whole," with 40.6% of students affected.

Misconception 1 was experienced by 58% of students, who assessed the temperature of objects based on their sense of perception. When students felt that the temperature of an object was cold, they assumed that the object had a low temperature. However, the coldness they felt was caused by the heat transfer rate from their hand or body to the object. When an object was in a room with a certain temperature, and when touched, it felt cold, its temperature was not lower than the room temperature; instead, the object's temperature was the same as the room temperature.

62.1% of students experienced Misconception 2, where they often made mistakes in distinguishing between temperature and heat. Students assumed that objects with high temperatures must contain more heat. However, it was possible for an object with a high temperature to contain less heat. This misconception aligns with the difference between temperature and heat: temperature is related to the kinetic energy of particles, while heat refers to the total thermal energy transferred. The lack of distinction between temperature and heat contributed to students maintaining this erroneous conception.

A total of 47.3% of students experienced misconceptions about objects that easily rise in temperature when heated being more difficult to cool down. Students assumed that an object that heated up quickly would take longer to cool down. However, based on the concept of specific heat capacity, it is the object's specific heat that determines how quickly it will absorb or release heat.

Most students experienced misconceptions 4 and 5 related to phase changes. They believed that heat was only used to increase temperature. In fact, in addition to increasing temperature, heat is also used to change the phase of a substance. These two misconceptions caused students to experience confusion about the concept of latent heat.

As many as 54% of students had misconceptions about the thickness of an object affecting the amount of heat absorbed. This misconception stemmed from students' misunderstanding of an object's conduction and heat capacity. Students believed that thick objects would absorb more heat, even though the thermal conductivity and the cross-sectional area of the object also needed to be considered.

A total of 54.4% of students experienced confusion regarding the relationship between mass, temperature, and heat. Students assumed that objects with greater mass would have a greater temperature increase when heated evenly. However, an object with a larger mass required more energy to increase its temperature compared to an object with a smaller mass, given the same amount of heat.

As many as 45.5% of students had misconceptions related to the sea and beach sand, assuming that both, when exposed to sunlight, must have the same temperature. This was based on the fact that most students needed to understand the concept of specific heat capacity, which can affect the temperature of an object or substance, even if both receive the same amount of heat.

Based on the questionnaire results, the misconceptions were mostly attributed to the learning process. The learning process that was typically applied involved student presentations without considering the material's depth level. Lecturers reinforced at the end, but even that did not significantly impact students' conceptions. Some lecturers conducted experiments to complement students' understanding, but only occasionally. Lecturers claimed that the material needed to be more dense, limiting the experimental experience. To improve students' understanding, lecturers also gave assignments in the form of practice questions. However, this had littlect the conceptions held by students. The lack of variety in the learning process led students to become more active and clear when arguing about a concept, which resulted in the learning process in the classroom not developing effectively. This contributed to students needing clarification so their understanding of concepts could have been maximized.

Figure 1 presents the number of students with misconceptions, categorized by gender, based on Table 2.

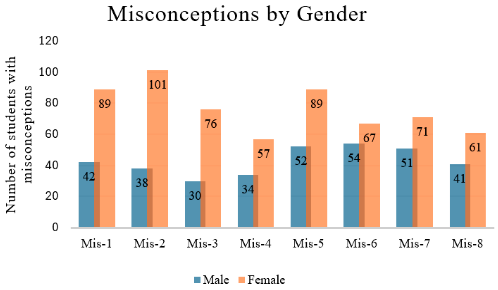

Figure 1 Misconceptions by gender

According to Figure 1, the most common misconception encountered by female students was Misconception 2, which stated that objects with elevated temperatures possessed greater thermal energy than those with lower temperatures. The misconception most frequently encountered by male students was Misconception 6, which suggested that the thickness of an object influenced the amount of heat it absorbed.

Based on Figure 1, male students exhibited fewer misconceptions than female students. This was attributed to the fact that male students generally demonstrated stronger skills in mathematics, visual reasoning, and practical field experience than their female counterparts (Kristyasari & Kusumaningrum, 2023). In contrast, female students tended to prefer solitary activities, such as those conducted indoors, including memorization tasks. As a result, female students were more likely to develop misconceptions than male students (Kristyasari & Kusumaningrum, 2023).

The causes of misconceptions are varied and complex, involving multiple factors contributing to misunderstanding concepts. One of the primary causes is everyday experiences that contradict the scientific concepts taught in class (Hermita et al., 2018; Saparni, Syuhendri, 2021; Ültay et al., 2021). Additionally, the learning process within the classroom environment is another factor that contributes to the development of misconceptions (Alfiana et al., 2021; Erceg et al., 2019; Hermita et al., 2018).

Misconceptions can also arise after students attend lessons in the classroom. Misconceptions originating from the school environment are referred to as school-made misconceptions (Barke & Büchter, 2023; Garba, 2015; Mubarokah et al., 2018). Lecturers with strong conceptual knowledge but inadequate selection of teaching methods can also contribute to the formation of misconceptions (Karabulut & Bayraktar, 2018; Linuwih et al., 2022). This represents an additional factor that contributes to the persistence of misconceptions. In some universities, the teaching process focuses on covering the material, often at the expense of the quality of instruction provided to students. This can, in turn, reinforce or perpetuate existing misconceptions among students.

Another factor contributing to their misconceptions is students' continued inability to modify their understanding and tendency to retain and memorize previously learned material (Gómez et al., 2020; Rohmah & Fadly, 2021). This aligns with research suggesting that misconceptions can be persistent, indicating that even when students are exposed to logical reasoning through experiments or direct observations that reveal their conceptual errors, it remains difficult to transform their preconceived notions into scientifically accurate understanding (Erceg et al., 2019; Oral & Gök, 2021).

The concepts of temperature and heat are abstract; therefore, the educational process should incorporate visual aids to make these concepts more concrete (Ning & Chongo, 2023; Sari et al., 2020). Additionally, it is essential to adopt a pedagogical approach that allows students to engage deeply with these concepts and apply their knowledge in authentic and relevant contexts (Bani-Salameh & Jelovica, 2018). Moreover, students often draw analogies between different events. Although phenomena in daily life may appear similar, they often involve distinct sets of concepts, even though they may fall under the same general category. Consequently, analogizing events in this manner can lead to misconceptions that persist in students' minds over time.

CONCLUSION

The data indicated that the prevalence of student misunderstandings varied across the different sub-topics of temperature and heat. The most prevalent misconception was found in the sub-topic, "The object with a higher temperature surely contains more heat compared to an object with a lower temperature." Several causes of misconceptions were identified, including everyday experiences that conflicted with scientific concepts, inaccuracies in teaching strategies, and insufficient depth of conceptual understanding. Therefore, lecturers needed to be careful in providing more detailed explanations about certain sub-topics and improving students' understanding of heat and temperature. Meanwhile, instructors were encouraged to explore appropriate teaching strategies for various conceptual designs, laboratories, and educational technologies that could be used to make learning more engaging.

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