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Misconceptions of Prospective Physics Teachers in Heat Concepts: Implementation of Three-Tier Diagnostic Tests (TTDT)

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ABSTRACT
Misconceptions about heat are still very common and need further research. Misconceptions experienced by prospective physics teachers must be immediately eliminated or reduced, because if misconceptions are left unchecked, these wrong concepts can persist for a long time and affect their teaching in the future. This study aims to identify misconceptions of prospective physics teachers on the concept of heat by applying the three-tier diagnostic test (TTDT). The approach used is descriptive quantitative with a conceptual diagnostic method. The research sample consisted of 52 7th-semester students of the Physics Education Department of Syiah Kuala University who had taken basic physics and thermodynamics courses. The research instrument consisted of 30 items, consisting of 10 content items, 10 reason items, and 10 confidence level items. Student responses were grouped into three categories: Understand the Concept (PK), Misconception (M), and Don't Understand the Concept (TPK). The results of the study showed variations in student understanding of the ten heat concepts tested. Overall, 67.7% of student responses were in the PK category, 28.3% in the M category, and 4% in the TPK category. The highest misconception was found in the concept of "Cold Objects Still Contain Heat (BDP)" and "Heat Exists in All Objects (PSB)", which is related to misconceptions about thermal energy at the microscopic level. Meanwhile, the concept of the definition of temperature and heat, the difference between the two, and the direction of heat transfer were the most widely understood concepts. The TTDT instrument was proven in identifying detailed categories of Understand the Concept (PK), Don't Understand the Concept (TPK), and Misconception (M).

Keywords: Diagnostic, Heat Concepts, Misconceptions, Three-Tier

Introduction

Many concepts in the physics curriculum are challenging for students to understand (Achor et al., 2022). Physics learning aims to assist students in acquiring concepts that are consistent with the literature and expert consensus (Rahayu, 2021; Simatupang et al., 2023). In physics, students must not only memorize formulas but also comprehend the significance of each subject. A person is considered to have an idea if they understand its actual meaning (Isra & Mufit, 2023). Understanding an object's definition, attributes, and components is considered conceptual knowledge. Students who have a good grasp of a subject are more likely to gain knowledge of other related concepts (Utami & Khotimah, 2023). In reality, students frequently have a distorted grasp of scientific topics, known as misconceptions (Rahayu, 2021; Sarini & Slamet, 2022).

These misconceptions impede the learning process (Fitri et al., 2023; Sarini & Slamet, 2022), since they might be deemed mistakes that make it harder for students to acquire and grasp new concepts (Mukramah et al., 2023). Misconceptions cause their own issues and must be addressed (Bani-Salameh, 2023). Misconceptions will disrupt succeeding concepts if not addressed swiftly, because physics material is interrelated (Fitri et al., 2023). Thus, misconceptions are no longer minor issues that can be overlooked in learning activities; instead, they must be investigated, and their causes and remedies explored.

Misconceptions can stem from a variety of reasons and may be broadly classified into five categories: students, lecturers/teachers, texts, context, and instructional techniques (Bhakti et al., 2022; Rahayu, 2021; Sarini & Slamet, 2022). Students bring to class knowledge gathered from everyday experiences, and if this previous knowledge is wrong, it might lead to misconceptions (Rahayu, 2021; Rismaningsih & Nurhafsari, 2022; Wancham et al., 2023; Zayyinah et al., 2022). Students who are disinterested in learning may pay less attention to the teacher's explanation, resulting in a decrease in conceptual comprehension (Fitri et al., 2023; Nurussama & Hermanto, 2022). Misconceptions experienced by prospective physics teachers must be immediately eliminated or reduced, because if misconceptions are left unchecked, these wrong concepts can persist for a long time and affect their teaching in the future.

Misconceptions can arise in all physics topics, including heat and thermodynamics (Isra & Mufit, 2023; Wiratama, 2022). The most prevalent physics misconceptions relate to particle dynamics, temperature-heat, waves, and energy (Budiyono et al., 2025). According to the findings of Zayyinah et al. (2022), the average misperception before remediation was 54.00%, with the biggest fallacy occurring in the indication of separating temperature from heat energy. This is because students have difficulty distinguishing between abstract concepts that are nearly identical (Zayyinah et al., 2022). In addition, the results of research by Obafemi & Aderonmu (2022) indicated that as many as 69% of students displayed mistakes in the issue of heat energy, where the most prevalent misconception occurred when distinguishing between temperature and heat. Based on the results of several studies, it can be concluded that misconceptions about heat are still very common and need further research.

Diagnostic tests are required to correctly identify misconceptions (Fitri et al., 2023; Rahayu, 2021). Diagnostic tests seek to identify students' flaws and strengths (Rahayu, 2021). Diagnostic test tools often used in scientific education include concept maps, open-ended surveys, photographs, word associations, interviews, and multiple-choice tests with two, three, and four tiers (Rokhim et al., 2023). In this study, a three-tier diagnostic test (TTDT) was utilized.

TTDT is a three-level version of a two-tier diagnostic exam that assesses students' confidence in their responses at the first and second tiers (Rahmadani et al., 2025). TTDT provides a simplified technique for distinguishing conceptual mistakes from limits in participants' knowledge or skills (Laeli et al., 2023). In addition, students can rate their confidence in the chosen solution (Muzakki et al., 2023).

Until this research was conducted, several studies identifying misconceptions using diagnostic tests on heat concepts had been conducted (Novita et al., 2025; Obafemi & Aderonmu, 2022; Oktavia et al., 2025; Septiyani & Nanto, 2021; Sukarelawan et al., 2021; Tanggira et al., 2022), but the research samples were students, not prospective physics teachers. Some studies identify the misconceptions of prospective physics teachers regarding the heat concept (Busyairi et al., 2022; Muliyani et al., 2024), but the number is still very minimal and was conducted outside the city of Banda Aceh. There is also research that analyzes the misconceptions of prospective physics teachers on the heat concept, but it does not use diagnostic tests; but uses a combination of observation, interviews, and document analysis methods (Novoa et al., 2024).

Therefore, this research aims to identify misconceptions among prospective physics teachers in Banda Aceh regarding the heat concept using TTDT. The novelty in this research lies in the research sample, research location, and research instruments.

Method

This research uses a quantitative descriptive approach with conceptual diagnostic methods. The instrument used is the three-tier diagnostic test (TTDT), which is designed to identify students' understanding of concepts, ignorance of concepts, and misconceptions regarding the concept of heat (Busyairi et al., 2022; Oktavia et al., 2025; Suliyanah et al., 2018; Tanggira et al., 2022). This approach was chosen because it has a high ability to differentiate between correct answers due to guessing and actual conceptual understanding. The sampling technique used is purposive sampling, which is based on certain considerations, namely selecting students who have identified misconceptions or who have studied the material (Fitri et al., 2023; Pouna et al., 2022; Sari & Mufit, 2023; Zayyinah et al., 2022).

The sample in this research was 52 students from the Department of Physics Education at Syiah Kuala University in the 7th semester of the 2025/2026 Academic Year. The sample was chosen because they had studied Temperature and Heat in basic physics courses and thermodynamics courses in the previous semester. This research was conducted in several steps as shown in Figure 1.

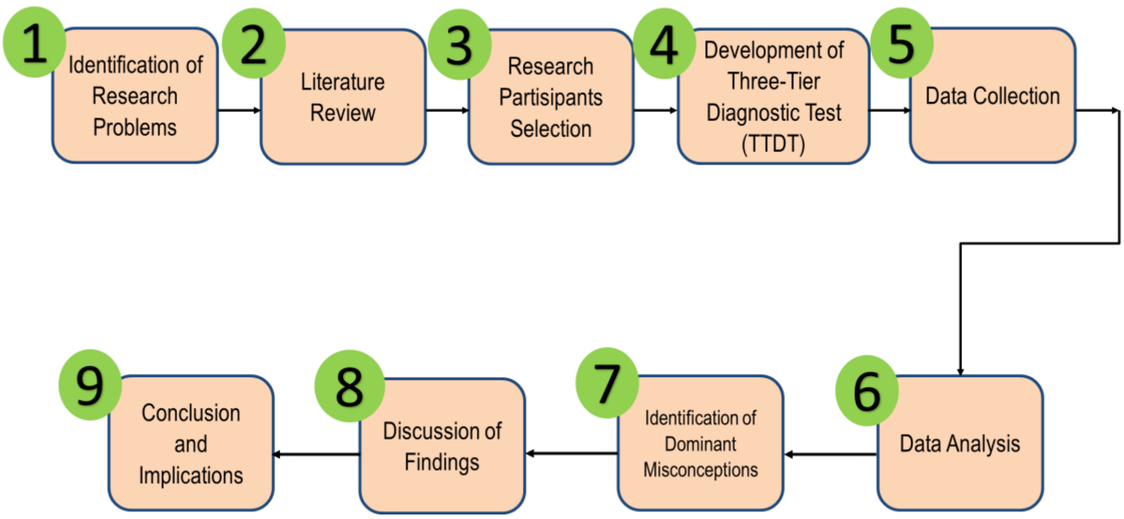

Figure 1. The Research Steps

Based on Figure 1 (fourth step), the diagnostic test instrument used in this research is a result of the development of research by Mustari et al. (2025), and the test instrument was still two-tier, with a total of 20 questions (10 items for content, and 10 items for reasons). The results of this research show that the item reliability is 0.92 and the item separation index is 3.47, which indicates high internal consistency and the ability of the instrument to differentiate item difficulty levels. The person–item map shows a moderate level of correspondence between student ability and item difficulty. The questions used contain 10 concepts to measure students' conceptual understanding. Table 1 shows the question number and the heat concept to be measured.

Table 1. The Concepts of Heat

Question Number	Concepts	Abbreviation
1	Difference between temperature and heat	PSP
2	Heat as energy, not a substance	PSE
3	Temperature vs. quantity of heat	SVK
4	Definition of heat and temperature	DPS
5	Heat exists in all objects	PSB
6	Cold objects still contain heat	BDP
7	Direction of heat transfer	APP
8	Specific heat capacity	KPJ
9	Thermal conductivity	KTR
10	Heat transfer through container material	PPW

In this research, the questions were developed into three tiers by adding 10 questions to determine the sample's level of confidence in the chosen answer. Thus, the total questions used was 30 items (10 items for content, 10 items for reasons, and 10 items for level of belief). Figure 2 depicts a two-tier question utilized in the research conducted by Mustari et al. (2025), whereas Figure 3 depicts a three-tier question devised by researchers and used in this study.

Concept: Difference between temperature and heat

1. **Tier 1:** Two objects of the same size have different temperatures: the first object has a temperature of 80°C and the second object has a temperature of 20°C. What can you conclude about the heat in these two objects?
   A. The object with the higher temperature has more heat.
   B. The object with the lower temperature has less heat.
   C. Temperature does not directly indicate the amount of heat in an object.
   D. Both objects have the same amount of heat because they are the same size.

2. **Tier 2:** Why did you choose that answer?
   A. Because heat is always directly related to the temperature of an object.
   B. Because the higher the temperature of an object, the more heat it has.
   C. Because heat depends on both temperature and size, but cannot be concluded from temperature alone.
   D. Because the size of an object determines the amount of heat it can store.

Figure 2. The Example of Two-Tier Diagnostic Question

Concept: Difference between temperature and heat

1. **Tier 1:** Two objects of the same size have different temperatures: the first object has a temperature of 80°C and the second object has a temperature of 20°C. What can you conclude about the heat in these two objects?
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   C. Temperature does not directly indicate the amount of heat in an object.
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2. **Tier 2:** Why did you choose that answer?
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   B. Because the higher the temperature of an object, the more heat it has.
   C. Because heat depends on both temperature and size, but cannot be concluded from temperature alone.
   D. Because the size of an object determines the amount of heat it can store.

3. **Tier 3:** Are you sure about your answer?
   A. Yes
   B. No

Figure 3. The Example of Three-Tier Diagnostic Question

Before identifying misconceptions in TTDT, it is necessary to classify the categories of conceptual understanding possessed by prospective physics teachers. Until the time this article was written, there were various numbers and terms of conceptual understanding categories in the TTDT (Arslan et al., 2012; Busyairi et al., 2022; Fikri et al., 2022; Oktavia et al., 2025; Tanggira et al., 2022; Zahriah & Fahira, 2025). However, in this research, the concept understanding categories were simplified into three categories (Understand the Concept, Misconception, and Don't Understand the Concept), as shown in Table 2 for the TTDT.

Table 2. Concept Understanding Categories on the TTDT

Answer (first-Tier)	Reason (Second-Tier)	Confidence (Third-Tier)	Category	Abbreviation
True	True	Sure	Understand the Concept	PK
True	False	Sure	Misconception	M
False	True	Sure	Misconception	M
False	False	Sure	Misconception	M
True	True	Not Sure	Don't Understand the Concept	TPK
True	False	Not Sure	Don't Understand the Concept	TPK
False	True	Not Sure	Don't Understand the Concept	TPK
False	False	Not Sure	Don't Understand the Concept	TPK

Table 2 shows that the level of conceptual understanding is determined by a combination of the correctness of the answer in the first tier, the accuracy of the reasoning in the second tier, and the respondent's confidence in the third tier. If a student provides a correct answer, provides a correct reason, and states they are sure, then they are categorized as understanding the concept (PK). This category indicates complete and consistent mastery of the concept.

Conversely, if a student answers correctly or incorrectly but provides an incorrect reasoning, but still states they are sure, then they are classified as having a misconception (M). This condition indicates a false understanding that the student believes to be correct, potentially hindering further learning.

Meanwhile, if a student states they are not sure about their answer, regardless of whether the answer or reasoning is correct or incorrect, then they are categorized as not understanding the concept (TPK). This category reflects cognitive uncertainty and weak conceptual mastery, although in some cases the answer and reasoning may be coincidentally correct.

Thus, this table serves as a diagnostic analysis framework to distinguish between correct conceptual understanding, deep-rooted misconceptions, and complete conceptual misunderstanding, making it highly relevant for use in science education research to identify the quality of students' conceptual understanding in more depth.

Then, the data were analyzed using descriptive percentage analysis techniques, namely calculating the number and percentage of each category:

$$P = \frac{f}{N} \times 100\%$$

Description:
P = Percentage of category
f = Frequency of answers in a particular category
N = Total sample

The analysis was carried out at two levels. First, per concept analysis is carried out with the aim of identifying the concepts that are best understood, the concepts that cause the most misconceptions, and the factors that cause misconceptions based on response patterns. Second, qualitative analysis is carried out to interpret the causes of misconceptions, connect findings with physics learning theories, and explain general phenomena that often trigger misconceptions.

Results and Discussion

Per-concept analysis shows quite large variations in understanding. A summary of the results can be seen in Figure 4. Based on Figure 4, it appears that the concepts that students understand best are DPS (N=46), PPW (N=44), and PSP (N=42). These three concepts have an understanding level of ≥ 80%. The concepts that cause the most misconceptions are BDP (N=48) and PSB (N=23). These findings show that misconceptions are not distributed evenly, but are concentrated in concepts related to the microscopic nature of changes in temperature and heat. This result aligned with Oktavia et al. (2025), concluded that the subconcepts with the highest misconceptions were the definition of temperature (44.4%) and heat and temperature changes (41.7%), where many students considered temperature as a measure of the amount of heat, so students still understood that only hot objects have heat.

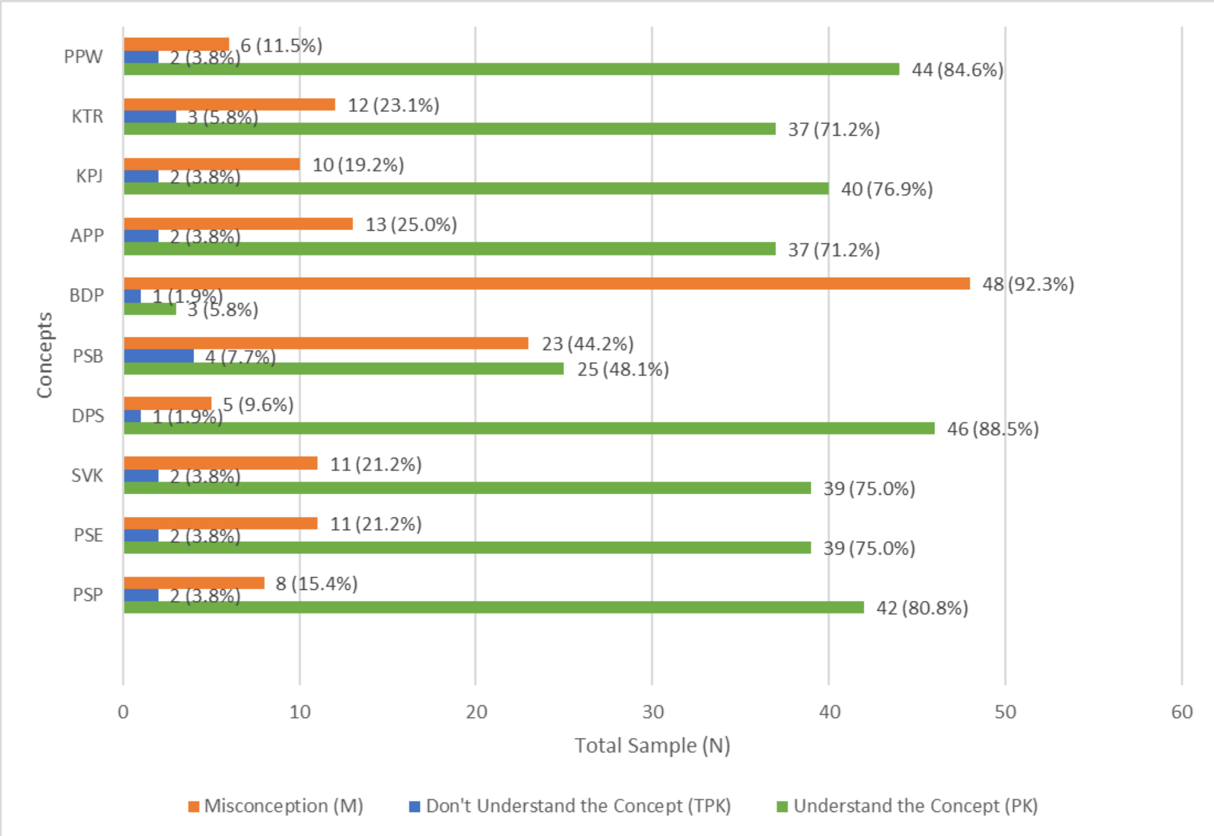

Figure 4. Graph of Recapitulation of Student Understanding per Concept

In the BDP concept, students assume that cold objects do not contain heat. This misconception arises from the simplification of everyday experiences, such as the phenomenon of hot air rising in convection. Students then generalize that heat is always in hot objects. In fact, heat transfer is universal, namely from objects with a higher temperature to a lower temperature until they reach thermal equilibrium. As long as the temperature of the object is above 0 Kelvin (-273 °C), the object still contains heat. Cold is just a relative perception; it does not mean it does not have energy. This result align with Novita et al. (2025), concluded that students believe that cold objects touching hot objects always absorb heat actively, not because of the temperature difference. This belief makes them believe that cold objects do not contain heat, and will only contain heat if they come into contact with a hot object.

In second place, misconceptions occur in the PSB concept. The concepts of BDP and PSB are very closely related because they both involve a basic understanding of thermal energy and particle movement, which students often do not obtain conceptually from the start. The research results of Obafemi & Aderonmu (2022) stated that 73% of misconceptions occurred in the concept of the kinetic theory of temperature, where students did not understand that temperature is related to the movement of particles (particle kinetic energy). These findings reinforce the notion that students' difficulties in grasping particle motion and thermal energy serve as a common conceptual barrier underlying both BDP and PSB. This close conceptual relationship explains why misconceptions in the PSB concept are prevalent, as insufficient understanding of thermal energy and particle motion directly affects students' comprehension of both PSB and BDP. Experiences when touching cold objects are often misinterpreted. Students feel that cold objects have no energy because they are cold, so they think they have no heat.

More than 80% of students have understood the concepts of DPS, PPW, and PSP. This means that the majority of prospective physics teachers understand the definitions of temperature and heat and their differences. They also understand that heat can be transferred. However, previous learning has overemphasized that heat moves from hot to cold. This statement is correct, but students often draw the wrong conclusion that if heat moves to cold, it means that cold objects have no heat at all. Inaccurate narratives from teachers, student worksheets, books, and even the internet often reinforce the idea that "hot objects = have a lot of heat," while "cold objects = have no heat." This results in two misconceptions at once: the disbelief that cold objects contain energy, and the disbelief that all objects contain heat energy. These misconceptions in both concepts reinforce each other. If students believe that "Cold objects do not contain heat," then they will automatically also believe that "Heat does not exist in all objects." Then, if students believe "Heat only exists in hot objects," then they will misunderstand that "Objects with low temperatures = zero energy = zero heat." As a result, these two indicators become the biggest points of misconception. Ultimately, students assume that temperature depends on the amount of heat energy, as relevant to the research findings of Septiyani & Nanto (2021), which stated that 76% of students misunderstood the definition of temperature, assuming it was a measure of the amount of heat energy. This finding is also supported by the research findings of Busyairi et al. (2022), which stated that 59.53% of misconceptions occurred in the concepts of temperature, heat, and thermal energy, where prospective physics teachers were unable to differentiate between temperature, heat, and thermal energy.

Overall, based on the results of the analysis of 52 prospective physics teachers and 10 questions with 10 heat concepts tested, it was found that 352 questions were in the PK category (67.7%). Meanwhile, 21 questions were in the TPK category (4%), and 147 questions were in the M category (28.3%). Figure 5 shows the average percentage of students' conceptual understanding.

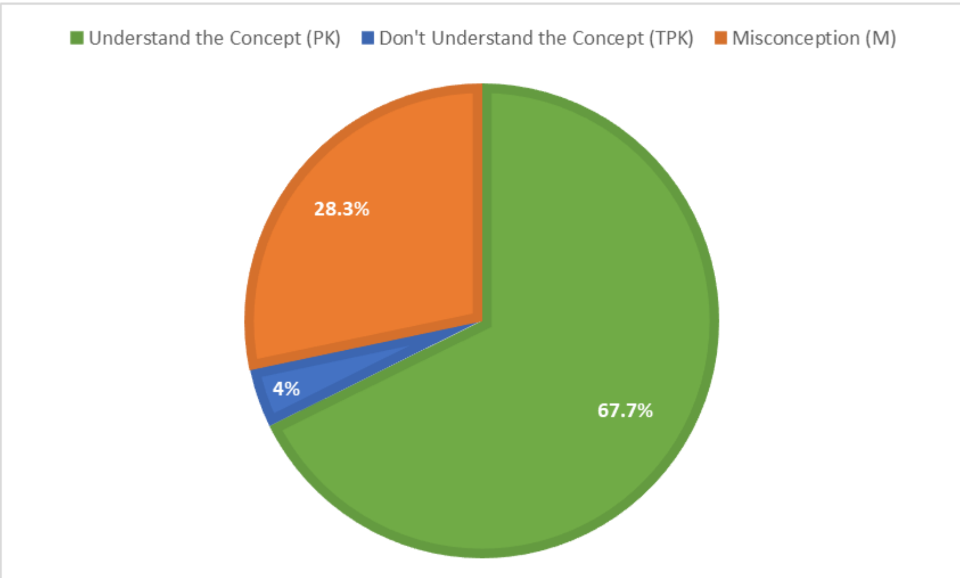

Figure 5. Average Percentage of Student Concept Understanding

Based on Figure 5, the percentage of misconceptions (28.3%) shows that prospective physics teachers still need to strengthen concepts through learning based on experiments, simulations, or physics demonstrations. Various previous studies have confirmed that misconceptions are persistent and cannot be effectively remediated through conventional learning alone, but rather require simulation-based learning, laboratory experiments and even visualization by virtual laboratory (Damayanti & Wulandari, 2025; Kotsis, 2024; Thalib et al., 2025). It is vital to employ microscopic level visualization in teaching the notion of heat, because it appears that easier visualization can assist students' grasp of the concept (Novita et al., 2025). Lecturers must pay serious attention to the remediation of misconceptions, because prospective physics teachers have the potential to pass on their misconceptions to students. Furthermore, high school students' misconceptions about the idea of heat arise frequently and need to be rectified (Nurvermadi et al., 2025). In other words, future physics teacher candidates must completely understand the concepts before they teach in class. Even though in this study the percentage of students who experienced misconceptions was smaller than those who understood the concept (28.3% < 67.7%), this was a big shame for them. This is due to their status as prospective physics teachers, no longer high school students.

According to Obafemi & Aderonmu (2022), there are various causes that generate misconceptions, including presentations by teachers, social interactions, prior knowledge, and textbooks and references. In addition, Busyairi et al. (2022) stated that the most common reasons for misconceptions are inaccurate beginning knowledge from ordinary experience and a lack of in-depth comprehension of the fundamental concepts of thermal physics, which leads to wrong interpretations of the events presented. Students who comprehend the physics of natural occurrences can overcome difficulties in their daily lives (Trisnasari & Oksiana, 2024). Therefore, the results in this study provide additional references to strengthen that misconceptions in prospective physics teachers are very fatal, because if prospective physics teachers do not understand the concepts or misconceptions, they will pass on this legacy to their students. This cycle will continue continuously if there is no attention and follow-up applied in the learning process.

Based on the analysis above, the TTDT used in this research is able to classify the conceptual understanding of prospective physics teachers in the Department of Physics Education for the 2025/2026 Academic Year, with three simplified categories, namely Understanding the Concepts (PK), Misconception (M), and Don't Understand the Concept (TPK). It is hoped that the results of this research can be a reference for writers for subsequent research, as well as for researchers out there who want to conduct similar research.

Conclusion

Based on the research results, prospective physics teachers showed a level of conceptual understanding of 67.7%, which falls into a fairly good category. However, the percentage of misconceptions remains relatively high at 28.3%, particularly in the concepts of "Cold Objects Still Contain Heat (BDP)" and "Heat Exists in All Objects (PSB)," both of which require a proper microscopic understanding of thermal energy that students have not yet fully developed. In contrast, other concepts, such as the definition of temperature and heat, the distinction between temperature and heat, and the direction of heat transfer, demonstrate a better level of understanding, while only 4% of students fall into the category of not understanding the concept. The TTDT instrument was proven in identifying detailed categories of Understand the Concept (PK), Don't Understand the Concept (TPK), and Misconception (M), thereby providing a comprehensive diagnostic profile of students' conceptual understanding. These findings indicate that systematic instructional efforts are still required, particularly through cognitive conflict-based remediation strategies, the use of microscopic-level visual simulations, and conceptual experiments to strengthen students' fundamental understanding. Given that the participants in this study are prospective physics teachers, enhancing their conceptual understanding should be a primary concern in teacher education programs to prevent the persistence and transmission of misconceptions to students at subsequent levels of learning.

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