Analysis of Pre-Service Science Teachers' Knowledge Construction on Heat and Matter State Changes Directions

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ABSTRAK

Penulisan ini bertujuan untuk menganalisis secara mendalam pemahaman konsep serta konstruksi pengetahuan mahasiswa calon guru IPA terhadap materi kalor dan perubahan wujud zat berdasarkan sumber internal, eksternal, dan both directions. Penelitian menggunakan pendekatan deskriptif kuantitatif dengan N (56) mahasiswa Program Studi Pendidikan IPA FKIP Universitas Tadulako semester genap tahun akademik 2025/2026 yang memiliki latar belakang pendidikan beragam. Instrumen berupa tes diagnostik konseptual disertai analisis sumber jawaban yang diklasifikasikan menjadi internal direction (ID), external direction (ED), dan both directions (BD). Data dianalisis menggunakan statistik deskriptif berupa persentase. Hasil penelitian menunjukkan bahwa pemahaman konsep mahasiswa berada pada kategori baik hingga sangat baik, dengan capaian tertinggi pada konsep menguap (98,21%) dan terendah pada konsep mengkristal (78,57%). Konstruksi pengetahuan mahasiswa didominasi oleh internal direction pada konsep kalor (53,57%), yang menunjukkan bahwa mahasiswa cenderung membangun pemahaman melalui penalaran konseptual dan pengalaman sebelumnya dibandingkan dengan hafalan. Namun, rendahnya proporsi both directions pada konsep menguap dan menyublim (12,50%) mengindikasikan bahwa integrasi antara pemahaman internal dan sumber eksternal ilmiah belum optimal.

Kata Kunci: *Konstruksi pengetahuan; perubahan wujud zat; calon guru sains.*

ABSTRACT

This study aims to analyze in depth the conceptual understanding and knowledge construction of pre-service science teachers on the topics of heat and changes in states of matter based on internal, external, and both directions. The research employed a quantitative descriptive approach involving 56 students from the Science Education Study Program, Faculty of Teacher Training and Education, Tadulako University, in the even semester of the 2025/2026 academic year, with diverse educational backgrounds. The instrument used was a conceptual diagnostic test accompanied by an analysis of answer sources, which were classified into internal direction (ID), external direction (ED), and both directions (BD). The data were analyzed using descriptive statistics in the form of percentages. The results showed that students' conceptual understanding was in the good to very good category, with the highest achievement in the concept of evaporation (98.21%) and the lowest in the concept of crystallization (78.57%). Students' knowledge construction was dominated by internal direction in the concept of heat (53.57%), indicating that students tend to build understanding through conceptual reasoning and prior experience rather than memorization. However, the low proportion of both directions in the concepts of evaporation and sublimation (12.50%) indicates that the integration between internal understanding and external scientific sources has not been optimal.

Keywords: *Knowledge construction; changes in states of matter; pre-service science teachers.*

INTRODUCTION

Science learning emphasizes conceptual understanding, scientific processes, and critical thinking skills in explaining natural phenomena. In science education, conceptual understanding is fundamental because it enables learners to understand relationships among phenomena and solve real-life problems. Students with strong conceptual understanding are able not only to recall information but also to interpret, explain, and apply concepts in various contexts (OECD, 2020). One essential topic in physics is heat and changes in states of matter, which explains many everyday phenomena.

These concepts include processes such as melting, freezing, evaporation, condensation, and sublimation. Understanding them is crucial because they relate to energy transfer, phase transitions, and the relationship between temperature and heat. However, prior studies show that these concepts are often difficult for students due to their abstract nature and the need for strong conceptual reasoning (Yeo & Zadnik, 2020). Conceptual understanding is not obtained through direct knowledge transfer but through an active process of knowledge construction. According to constructivist theory, learners build knowledge based on prior knowledge, learning experiences, and interactions with their environment, resulting in variations in understanding among individuals (Schunk, 2020).

In higher education, particularly in Science Education programs, students often come from diverse educational backgrounds, including science, social sciences, language studies, and vocational schools. This diversity influences students' prior knowledge of physics concepts. Students from science backgrounds tend to have more exposure to physics, while others may have limited experience (Fitriani et al., 2022). These differences affect how students construct their understanding. Some students develop scientifically accurate concepts, while others experience misconceptions, particularly in understanding the relationship between heat, temperature, and phase changes (Putri & Widodo, 2021). Therefore, analyzing students' knowledge construction is essential to assess their level of conceptual understanding.

To investigate knowledge construction, appropriate instruments are required. One effective method is using digital survey tools such as Google Forms, which facilitate data collection, processing, and flexible responses (Rahmawati & Nurhayati, 2023). Through well-designed conceptual questions, researchers can evaluate students' understanding across different indicators.

Knowledge construction is an active process in which learners build new understanding based on prior knowledge. Learners actively process information through experience, social interaction, and reflection, leading to deeper conceptual understanding (Schunk, 2020). Constructivist theory emphasizes that knowledge cannot be directly transferred from teachers to students but must be constructed independently. Therefore, effective learning should involve exploration, discussion, and problem-solving activities (Huang et al., 2020). In science education, this process is particularly important because many concepts are abstract and require strong conceptual integration (Widodo et al., 2021).

Constructivism also highlights the importance of active learning and the role of teachers as facilitators. Jean Piaget explained that cognitive development occurs through assimilation and accommodation. Assimilation involves integrating new information into existing cognitive structures, while accommodation involves modifying these structures when new information does not fit prior knowledge (Schunk, 2020). In science learning, this means that students construct understanding through interaction with their environment and experiences (Fitriani et al., 2022).

Lev Vygotsky emphasized the role of social interaction in knowledge construction. His concept of the Zone of Proximal Development (ZPD) describes the gap between what learners can achieve independently and with assistance from more knowledgeable individuals (Schunk, 2020). Through collaboration, discussion, and scaffolding, learners can develop deeper understanding. Instructional approaches involving group work and guided support are therefore effective in enhancing conceptual learning (Widodo et al., 2021; Huang et al., 2020).

Understanding heat and changes in states of matter is essential because these concepts are closely related to everyday phenomena.

Heat is a form of energy transferred due to temperature differences, affecting the kinetic energy of particles and causing temperature changes or phase transitions (Yeo & Zadnik, 2020). Changes in states of matter occur through heat absorption or release, involving processes such as melting, freezing, evaporation, condensation, and sublimation. These concepts are also related to latent heat, which is required to change a substance's state without altering its temperature (Putri & Widodo, 2021).

This study aims to describe students' knowledge construction in science learning, identify the tendencies of knowledge sources used, and determine which dimensions need improvement. The findings are expected to provide insights into students' conceptual understanding and contribute to the development of more effective physics learning strategies.

LITERATURE REVIEW

Science learning is a process that emphasizes the mastery of concepts, science process skills, and the development of scientific attitudes in understanding natural phenomena (Schunk, 2020). It is not only oriented toward outcomes in the form of knowledge, but also toward the processes through which that knowledge is acquired, such as observation, experimentation, and scientific reasoning. Through science learning, students are expected to develop critical, analytical, and systematic thinking skills in solving problems related to everyday life. Therefore, science instruction should be designed in a contextual and activity-based manner so that students can construct deep and meaningful conceptual understanding (Putri & Widodo, 2021).

Science learning highlights the importance of students' active involvement in the learning process through a constructivist approach. In this approach, students do not passively receive information but actively construct knowledge based on prior knowledge, learning experiences, and interactions with their environment and peers (Widodo et al., 2021). Teachers act as facilitators who create a learning environment that supports exploration, discussion, and problem-solving. Thus, effective science learning can help students connect scientific concepts with real-life phenomena, thereby enhancing conceptual understanding as well as higher-order thinking skills (Yeo & Zadnik, 2020).

METHOD

This study employed a quantitative approach with a descriptive research design. The descriptive quantitative approach was used to examine students' knowledge construction related to the concepts of heat and changes in states of matter based on survey data collected through a Google Forms-based instrument. This approach was selected because the data consisted of respondents' answer scores, which were subsequently analyzed using descriptive statistical techniques, such as percentages, to describe the level of students' understanding for each conceptual indicator.

The study was conducted among students of the Science Education Study Program, Faculty of Teacher Training and Education, Tadulako University, during the even semester of the 2025/2026 academic year, from February to March 2026. The research subjects consisted of 56 students with diverse secondary education backgrounds, including science, social sciences, and vocational high school graduates. These variations in background may influence differences in students' prior knowledge regarding the concepts of heat and changes in states of matter.

Data were collected using a survey method with an instrument in the form of multiple-choice questions distributed through the Google Forms platform. The research instrument consisted of 10 items developed based on indicators of heat and changes in states of matter. Each item was designed to measure students' level of understanding according to predetermined indicators. The use of Google Forms was chosen to facilitate the distribution of the instrument and to ensure efficiency in data collection and processing.

The data were analyzed using quantitative descriptive analysis techniques. The analysis was carried out by calculating students' scores for each item and then converting them into percentages to determine the level of understanding for each conceptual indicator. Scoring was assigned as follows: correct answers were given a score of 1, and incorrect answers were given a score of 0. Furthermore, the percentage of understanding was calculated using the following formula:

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

Where:
P is represents the percentage of the level of understanding.
f is the number of correct answers.
N is the number of respondents.

The percentage results were then categorized based on the criteria of the level of understanding as follows Table 1.

Table 1. Percentage categories

Percentage	Category
81-100%	Very good
61-80%	Good
41-60%	Fair
21-40%	Poor
0-20%	Very poor

RESULTS

This study involved 56 students from the Science Education Study Program, Faculty of Teacher Training and Education, Tadulako University, in the even semester of the 2025/2026 academic year. The students had diverse educational backgrounds, including science, social sciences, vocational high school, and other educational pathways. This diversity provides an overview of students' knowledge construction derived from their prior learning experiences. However, differences in background may still influence how students construct knowledge. Students from science backgrounds tend to have a stronger conceptual foundation, whereas those from social sciences or vocational backgrounds may rely more on practical experience or memorization. This indicates that the learning process in higher education can reduce gaps in prior knowledge arising from different educational backgrounds. This finding is consistent with Widodo (2021), who reported that differences in school background do not always have a significant effect on students' conceptual understanding after participating in science learning at the university level.

Data analysis was conducted on students' understanding of the concepts of heat and changes in states of matter, as well as on the sources of their knowledge construction, which include internal direction (ID), external direction (ED), and both internal–external direction (BD).

Conceptual Understanding Based on Content Indicators

Based on the results of the indicator analysis, the overall level of students' conceptual mastery falls within the good to very good categories. The percentage of conceptual mastery for each indicator is presented in the following Table 2.

Table 2. Percentage of conceptual understanding based on content indicators

Indicator	Correct score	Maximum score	Percentage	Category
Heat	192	224	85.71	Very good
Melting	53	56	94.64	Very good
Freezing	51	56	91.07	Very good
Evaporation	55	56	98.21	Very good
Condensation	51	56	91.07	Very good
Sublimation	52	56	92.86	Very good
Crystallization	44	56	78.57	Good

Analysis of Item Mastery

The results of the item analysis indicate that most students were able to answer the questions correctly with a high level of success. The percentage of correct responses ranged from 75% to 98.21% (Table 3). Items related to phase change concepts that can be easily observed empirically tend to have higher percentages of correct answers compared to more abstract concepts, such as crystallization processes or the concept of heat energy at the microscopic level.

Table 3. Percentage of test items

Concept	Item	Correct answers		Incorrect answer	
		Total	Percentage	Total	Persentase
Heat	1	51	91.07	5	8.93
	2	42	75.00	14	25.00
	3	47	83.93	9	16.07
	4	52	92.86	4	7.14
Melting	5	53	94.64	3	5.36
Freezing	6	51	91.07	5	8.93
Evaporation	7	55	98.21	1	1.79
Condensation	8	51	91.07	5	8.93
Sublimation	9	52	92.86	4	7.14
Crystallization	10	44	78.57	12	21.43

Students' Knowledge Construction

Students' knowledge construction was analyzed through three categories of answer sources (Table 4). Based on the analysis of students' responses, the sources of knowledge construction can be classified into three categories: (1) internal direction, (2) external direction, and (3) both directions. The results indicate that most students tend to use internal direction when answering the questions. This suggests that students do not merely rely on memorization, but have engaged in independent knowledge construction through conceptual understanding.

Most students appeared to rely on their own reasoning when formulating answers. They did not simply repeat information but tried to interpret the questions based on what they already understood. In many responses, students connected different concepts rather than stating isolated facts. This pattern shows that they were making sense of the material in a personal way. Some answers also included explanations in their own words, which indicates that the ideas had been processed rather than copied.

Students who used internal direction often showed more confidence in their answers. Even when their responses were not entirely correct, they still attempted to explain the reasoning behind their choices. This suggests that they were actively thinking about the concepts instead of depending only on what had been taught.

Table 4. Percentage of sources of answers

Concept	Item	Answer			Percentage (%)		
		ID	ED	BD	ID	ED	BD
Heat	1	20	23	13	35.71	41.07	23.21
	2	24	18	14	42.86	32.14	25.00
	3	30	16	10	53.57	28.57	17.86
	4	25	16	15	44.64	28.57	26.79
Melting	5	28	20	8	50.00	35.71	14.29
Freezing	6	28	16	12	50.00	28.57	21.43
Evaporation	7	30	19	7	53.57	33.93	12.50
Condensation	8	25	17	14	44.64	30.36	25.00
Sublimation	9	29	20	7	51.79	35.71	12.50
Crystallization	10	25	18	13	44.64	32.14	23.21

DISCUSSION

The results of the study indicate that students' understanding of the concepts of heat and changes in states of matter falls into the very good category. The concept of evaporation shows the highest level of understanding (98.21%), while the concept of crystallization has the lowest percentage (78.57%). These findings suggest that pre-service science teachers have a sufficiently strong conceptual foundation in basic physics topics.

The high level of understanding in phase change concepts such as evaporation, melting, and freezing indicates that concepts directly related to everyday phenomena are easier for students to comprehend. This is consistent with constructivist theory, which states that knowledge is constructed through the interaction between prior experiences and new information.

These results are supported by the study of Park & Cho (2022), which shows that students tend to understand contextual science concepts more easily than abstract ones. In addition, students' understanding of physics concepts improves significantly when the material is related to their real-life experiences. This indicates that empirical experience plays an important role in students' knowledge construction process.

In contrast, the concept of crystallization has a lower level of understanding compared to other indicators. This may be because the concept is rarely observed directly in everyday life and requires an understanding of microscopic processes at the particle level. Research by Gurel et al. (2020) shows that heat energy and phase change concepts often become sources of conceptual difficulty due to their reliance on microscopic representations that are difficult to visualize. This finding is also supported by Docktor & Mestre (2016), who state that students' difficulties in understanding physics concepts often arise in topics that require abstract representation and microscopic modeling. Furthermore, Bächtold (2018) emphasizes that the lack of connection between macroscopic and microscopic representations is a major cause of learning difficulties in phase change concepts.

Phase change concepts that are frequently observed, such as melting, freezing, and evaporation, show understanding levels above 90%. This suggests that direct experience plays a significant role in the construction of scientific knowledge. Taber (2019) found that experience-based learning helps learners develop more stable conceptual understanding and reduces misconceptions. From a constructivist perspective, knowledge is built through the interaction between prior experience and new information. Students do not come with "empty minds," but rather bring initial schemas formed through their life experiences and previous education. Vosniadou (2019) also highlights that prior knowledge plays a crucial role in shaping how individuals understand new scientific concepts.

Pre-service science teachers who have strong empirical experiences related to a phenomenon tend to develop more stable conceptual understanding. This is supported by Garner et al. (2018), who state that deep conceptual understanding occurs when individuals are able to integrate empirical experiences with their existing cognitive structures. Furthermore, Gurel et al. (2020) suggest that understanding of heat and phase change concepts can be improved through instructional approaches that emphasize visualization and conceptual representation. This indicates that appropriate teaching strategies are essential to help students understand abstract concepts.

Thus, the findings of this study not only describe students' level of understanding but also reinforce that direct experience, prior knowledge, and the ability to connect macroscopic and microscopic representations play important roles in students' knowledge construction regarding heat and changes in states of matter.

The dominance of the internal direction category indicates that most students construct knowledge through conceptual understanding and scientific reasoning processes. This is a positive indicator in science learning, especially for pre-service teachers who will later teach scientific concepts to students. This finding is consistent with García-Martínez & Fraser (2022), who state that knowledge construction based on internal understanding enables students to develop deeper conceptual understanding and enhances critical thinking skills. This result is also supported by Chi (2018), who explains that learning involving active cognitive engagement (active constructive learning) leads to deeper understanding compared to passive learning.

Students who use internal direction are generally able to relate concepts to their experiences, provide scientific explanations, apply cause-and-effect reasoning, and transfer concepts to new situations. This aligns with Bransford et al. (2018), who emphasize that strong conceptual understanding enables knowledge transfer to new contexts. In contrast, the external direction category indicates that students rely on external sources such as memorization, textbooks, or lecturers' explanations without deep understanding. This category still appears in several concepts, particularly those that are abstract. Mayer (2017) also found that learning based solely on receiving information without active cognitive processing is ineffective in developing deep conceptual understanding.

The both directions category represents a combination of internal understanding and external references. This category is considered ideal in modern science learning because it reflects students' ability to understand concepts while also utilizing scientific sources to strengthen their understanding. However, in this study, the proportion of both directions is still relatively low. This suggests that the integration between conceptual understanding and the use of external sources, such as scientific literature, needs to be strengthened.

This study shows that students who are able to integrate knowledge from multiple sources tend to have more flexible and deeper understanding compared to those who rely on a single source. Therefore, although students demonstrate a strong tendency toward internal direction, the ability to integrate knowledge (both directions) still needs improvement. Learning in teacher education programs should thus be designed to encourage students not only to construct understanding independently but also to critically and reflectively integrate various scientific sources.

The findings also indicate that most pre-service science teachers still possess significant misconceptions related to heat and changes in states of matter, particularly in distinguishing between heat and temperature and in understanding energy transfer processes (Acemioğlu & Doğan, 2019; Laksana, 2016). This is consistent with previous studies identifying common misunderstandings among pre-service teachers regarding heat and temperature (Acemioğlu & Doğan, 2019; Rasul et al., 2019). These misconceptions range from low to high levels and fundamentally hinder their ability to accurately explain physical phenomena (Uyuni et al., 2024). Consequently, this condition may negatively impact the quality of future science education, as teachers with incorrect conceptual understanding are likely to transfer these misconceptions to their students (Rohmah et al., 2023).

Therefore, identifying and addressing misconceptions is crucial to ensure that pre-service science teachers have a strong conceptual foundation before entering the teaching profession (Mubaqi et al., 2018; Rahmawati et al., 2019). This study highlights the need for targeted pedagogical interventions, such as multi-representational teaching strategies, which have been shown to effectively improve conceptual understanding in physics (Mulhayatiah et al., 2022). In-depth interviews also reveal that misconceptions often originate from prior learning experiences or misinterpret-tation of information (Fauziah & Ananda, 2023).

Interview data indicate that many pre-service teachers struggle to distinguish between heat and temperature, suggesting that intuitive perceptions of hot and cold still dominate without a proper understanding of energy transfer (Winarti et al., 2017). Some students even consider temperature as an intrinsic property unaffected by heat addition or removal, reflecting incomplete understanding of the relationship between thermal energy and thermodynamic states (Atmojo et al., 2024). These misunderstandings are further reinforced by students' tendency to rely on intuitive thinking, which often conflicts with scientific principles (Kamilah et al., 2025).

Previous studies confirm that thermodynamics concepts, including heat and temperature, are among the most difficult topics for students and frequently lead to persistent misconceptions (Pasaribu & Irfandi, 2023; Thiam, 2021). Data show that 51.22% of pre-service teachers experience moderate levels of misconcep-tions in temperature and heat concepts (Taqwa et al., 2020). These misconceptions extend beyond definitions to the application of physical phenomena, such as phase changes often incorrectly associated with temperature change rather than latent heat (Thiam, 2021). Such misconceptions can significantly affect subsequent learning, as reflected in generally low achievement in thermodyna-mics topics (Azizah et al., 2020).

Students of the Science Education Program at the Faculty of Teacher Training and Education, Tadulako University, demonstrate conceptual mastery of heat and changes in states of matter in the good to very good category. Concepts related to everyday experiences show higher levels of understanding compared to more abstract concepts. Students' knowledge construction is dominated by internal direction (47%), indicating that most students construct understanding independently. External direction accounts for 33%, mainly in difficult or unfamiliar concepts, while both directions account for 20%, indicating that integration between internal and external knowledge still needs improvement.

This study confirms the prevalence of fundamental misconceptions related to heat and changes in states of matter among pre-service science teachers. These findings are consistent with previous studies highlighting difficulties in distinguishing between heat, temperature, and internal energy (Winarti & Budiarti, 2020; Wulandari et al., 2023). This indicates that understanding basic thermod-ynamics concepts remains a significant challenge, even for students preparing to become science educators (Alwan, 2011; Fenditasari et al., 2020; Jasien & Oberem, 2002). These difficulties often stem from students' inability to differentiate between thermodynamic concepts, even after traditional lecture-based instruction (Sarıçayır et al., 2016).

CONCLUSION

The findings of this study indicate that pre-service science teachers demonstrate a good to very good level of understanding of heat and changes in states of matter. Concepts closely related to everyday experiences, such as evaporation, melting, and freezing, show higher levels of comprehension compared to more abstract concepts like crystallization. This highlights the important role of empirical experience and real-life context in facilitating the construction of scientific knowledge. Furthermore, students' knowledge construction is predominantly characterized by internal direction, suggesting that most learners are capable of developing understanding through conceptual reasoning and personal experience. However, the integration between internal understanding and external sources (both directions) remains relatively limited, indicating the need for instructional strategies that promote critical engagement with scientific literature and multiple learning resources. The study also reveals the persistence of misconceptions, particularly in distinguishing between heat and temperature and in understanding energy transfer processes. These misconceptions may negatively affect future teaching quality if not properly addressed, given that these students will become science educators. Therefore, targeted pedagogical interventions, such as multi-representational approaches and visualization techniques, are essential to enhance conceptual understanding. In conclusion, this study emphasizes the importance of experiential learning, strong conceptual representation, and the integration of diverse knowledge sources in improving the mastery of fundamental physics concepts among pre-service science teachers.

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