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Scientific Reasoning Skills in Physics Education: A Preliminary Analysis of High School Students' Competence in Temperature and Heat

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Abstract:

Scientific reasoning skills play a crucial role in understanding physics concepts through cause–effect analysis and evidence-based reasoning. However, physics learning that remains predominantly focused on problem-solving tasks has resulted in students being less accustomed to engaging in systematic scientific thinking. This study aims to analyze and describe the level of scientific reasoning skills of high school students on the topic of temperature and heat as an initial effort to map their scientific reasoning profiles. The research employed a quantitative descriptive method with 36 twelfth-grade students from a public senior high school in Tasikmalaya as participants. The research instrument consisted of a two-tier multiple-choice test developed based on Lawson's six indicators of scientific reasoning, namely conservation reasoning, proportional reasoning, control of variables, probability reasoning, correlation reasoning, and hypothetical-deductive reasoning. The results indicate that students' scientific reasoning skills are still within the moderate category, with an average score of 51.85, suggesting that their scientific thinking skills have not yet developed optimally. The indicator-based analysis shows the highest achievement in control of variables and the lowest in correlation reasoning and hypothetical-deductive reasoning, indicating that students are more capable of engaging in concrete reasoning than in abstract and deductive reasoning. These findings emphasize the need for physics instruction that provides a greater opportunity for scientific reasoning activities. The Creative Problem Solving model is recommended because it has the potential to facilitate critical, creative, and evidence-based thinking in solving physics problems.

1. Introduction

The development of 21st-century education plays a central role in encouraging students to think scientifically, critically, and reflectively in understanding the phenomena that occur within it (Chusna et al., 2024). A fundamental cognitive ability that underpins meaningful learning is scientific reasoning skills, defined as the capacity to reason scientifically by integrating concepts, analyzing causal relationships, and formulating evidence-based conclusions (Firdaus et al., 2021). Within the framework of the current national curriculum, this ability represents a crucial element of deep learning implementation. Deep learning directs students toward learning outcomes that prioritize conceptual understanding and the ability to link knowledge to authentic applications (Zebua, 2025). This aligns with the Regulation of the Directorate General of Primary and Secondary Education of the Republic of Indonesia (Permendikdasmen) No. 13 of 2025, which emphasizes deep learning as a means to achieve the eight dimensions of the graduate profile, including collaboration, which is strongly associated with scientific reasoning skills. Scientific reasoning skills encompass six dimensions of scientific reasoning according to Lawson, namely conservation reasoning, proportional reasoning, control of variables, probability reasoning, correlation reasoning, and hypothetical-deductive reasoning (Lawson, 2004). Collectively, these six aspects reflect a scientific thinking process anchored in analytical, logical, and evidence-based reasoning, making them a fundamental foundation for learning physics.

Scientific reasoning skills occupy a pivotal position in fostering scientific literacy and problem-solving competence, both of which constitute key competencies assessed by the Programme for International Student Assessment (PISA). Based on the 2022 PISA results, students in Indonesia obtained scores still below average, with 366 in mathematics, 359 in reading, and 383 in science (OECD, 2023). These findings suggest that the scientific reasoning skills of Indonesian students remain at a low level. Within the context of physics education, scientific reasoning skills constitute a fundamental basis for enabling students to comprehend abstract concepts, relate theoretical principles to empirical phenomena, and cultivate a critical scientific mindset toward natural occurrences (Pascaeka et al., 2023). Therefore, reinforcing scientific reasoning skills is an urgent imperative in physics education to ensure that students not only understand formulas or computational procedures, but are also capable of constructing the scientific meaning underlying each concept they learn in a deep and meaningful way. Physics constitutes a strategically significant subject, as it directly engages students in analyzing natural phenomena that are closely connected to their daily lives (Firdaus et al., 2021). Physics is not merely a collection of mathematical equations, but encompasses various concepts that students must understand in order to apply physics knowledge in real life (Parinduri et al., 2025). However, in practice, physics is frequently regarded as a difficult, complicated, and unenjoyable subject, causing many students to lose interest in it. Consequently, a considerable number of students struggle in learning physics, which in turn adversely affects their scientific reasoning skill attainment (Anjiana et al., 2024).

Previous studies have also reported that the scientific reasoning skills of students in Indonesia are still within the low category (Lestari et al., 2013). Research conducted across multiple educational levels demonstrates that the majority of students are still unable to employ scientific reasoning effectively in understanding physics concepts, especially when identifying relationships between variables, constructing hypotheses, and deriving conclusions from empirical evidence (Anjani et al., 2020). In practice, classroom physics instruction continues to be dominated by memorization of formulas and the execution of computational procedures, with little emphasis on deep scientific reasoning. Consequently, students are inadequately trained to conceptualize natural phenomena and are likely to encounter difficulties when faced with physics problems that demand analytical thinking (Yusa et al., 2022). Existing studies predominantly evaluate scientific reasoning within the broader context of science subjects, whereas research that explicitly measures and characterizes students' scientific reasoning skills in the specific context of temperature and heat is still scarce. Yet, temperature and heat are concepts that frequently trigger misconceptions, as they demand abstract understanding and rely heavily on higher-order logical reasoning skills (Hara et al., 2023). Therefore, a preliminary study is required to map the profile of students' scientific reasoning skills on this topic, serving as a foundation for the development of more effective and meaningful physics instructional strategies.

The choice of temperature and heat as the context of this study is grounded in the abstract nature of these concepts, which require advanced scientific reasoning skills (Mubarokiyah et al., 2024). Temperature and heat are among the most challenging topics for students due to their abstract nature and the logical reasoning demands required to comprehend them (Suciati et al., 2024). The concepts of temperature and heat are not merely associated with the measurement of physical quantities; rather, they require a comprehensive understanding of thermal energy interactions, energy transformations, and heat transfer processes that take place in daily life. Nevertheless, students frequently develop misconceptions when attempting to differentiate between temperature and heat (Kapul et al., 2023). This condition demonstrates that instruction on this topic cannot be limited to procedural approaches; rather, it necessitates scientific reasoning skills to enable students to rationally and evidence-based understand the interrelationships among concepts such as temperature, thermal expansion, heat energy, heat transfer, and thermal equilibrium (Siahaan et al., 2025). These skills are not only important for mastering the topic of temperature and heat, but can also serve as an indicator of students' readiness to understand other, more complex physics concepts, such as thermodynamics, energy, and changes of state. Thus, examining scientific reasoning skills in the context of temperature and heat becomes highly relevant for strengthening conceptual understanding and establishing a foundation for scientific thinking in physics learning.

In this study, scientific reasoning skills are conceptually framed as a set of cognitive processes that enable students to construct meaningful understanding of temperature and heat through systematic reasoning rather than memorization of formulas. Each of Lawson's indicators is theoretically connected to core thermal concepts: conservation reasoning supports understanding of energy conservation in heat transfer, proportional reasoning underlies temperature change and heat capacity, control of variables is essential in analyzing thermal experiments, correlation reasoning helps identify relationships among thermal variables, and hypothetical-deductive reasoning enables students to formulate and test explanations about thermal phenomena. Therefore, the measurement of scientific reasoning skills in this study is intended to map how students employ scientific reasoning when engaging with the conceptual structure of temperature and heat, providing a basis for interpreting students' reasoning profiles and for designing more effective physics learning in future studies.

Drawing from the above rationale, this study aims to analyze and describe senior high school students' scientific reasoning skills on the topic of temperature and heat as a diagnostic profile of students' reasoning in abstract physics concepts. This preliminary investigation is intended not only to map students' reasoning abilities in a local school context, but also to contribute to the broader understanding of how learners engage with thermally based scientific reasoning. The results are expected to provide empirical evidence that can inform the design of physics instruction and assessment practices aimed at strengthening scientific reasoning across diverse educational settings, as well as serve as a reference for teachers, researchers, and curriculum developers in developing more effective and meaningful physics learning.

2. Literature Review

Scientific reasoning skills have been widely recognized as a core component of scientific literacy and higher-order thinking in science education. In physics learning, these skills enable students to interpret physical phenomena, construct causal explanations, and evaluate evidence-based conclusions (Lawson, 2004; Firdaus et al., 2021). Previous research has shown that students' ability to reason scientifically plays a decisive role in their conceptual understanding, particularly in topics that require abstract and multivariable reasoning, such as thermodynamics, temperature, and heat (Mubarokiyah et al., 2024).

Several empirical studies have reported that students' scientific reasoning skills in Indonesia remain at a low to moderate level. Secondary school students struggle to apply proportional and hypothetical-deductive reasoning when solving science problems. Similarly, Anjiana et al. (2024) showed that students experience difficulties in identifying relationships between variables and in constructing hypotheses based on empirical data. These findings indicate that students often rely on surface-level procedures rather than engaging in deeper scientific reasoning processes. In physics classrooms, learning is still frequently dominated by formula memorization and algorithmic problem solving, which limits opportunities for students to practice reasoning, argumentation, and evidence-based thinking (Yusa et al., 2022).

Research focusing specifically on physics topics has further demonstrated that abstract concepts such as temperature and heat pose substantial challenges for students. Kapul et al. (2023) reported that many students fail to distinguish between temperature and heat, leading to persistent misconceptions. Suciati et al. (2024) also found that students tend to interpret thermal phenomena in intuitive rather than scientific ways, particularly when reasoning about energy transfer and thermal equilibrium. These difficulties are closely related to weaknesses in scientific reasoning, especially in correlation reasoning and hypothetical-deductive reasoning, which are required to connect variables such as temperature, mass, heat, and energy change (Siahaan et al., 2025).

From a theoretical perspective, Lawson's framework of scientific reasoning provides a comprehensive model for understanding how students develop scientific thinking. Lawson (2004) conceptualizes scientific reasoning as consisting of six interrelated dimensions: conservation reasoning, proportional reasoning, control of variables, probability reasoning, correlation reasoning, and hypothetical-deductive reasoning. These dimensions reflect a progression from concrete reasoning toward more abstract and formal thinking, which is essential for understanding complex physics concepts. In the context of temperature and heat, conservation reasoning supports understanding of energy conservation, proportional reasoning underlies relationships such as heat capacity and temperature change, control of variables is necessary for interpreting thermal experiments, and hypothetical-deductive reasoning enables students to generate and test explanations about thermal processes.

Based on this framework, scientific reasoning skills can be viewed as the cognitive bridge between empirical observations and theoretical physics concepts. When students possess well-developed scientific reasoning, they are more capable of interpreting experimental data, identifying patterns among thermal variables, and constructing valid explanations for physical phenomena. Conversely, limited scientific reasoning leads students to rely on rote procedures and fragmented knowledge, which contributes to misconceptions and superficial understanding.

Although previous studies have examined scientific reasoning in general science contexts, research that specifically maps students' scientific reasoning profiles in the topic of temperature and heat remains limited. Most existing studies focus on learning outcomes or misconceptions without explicitly analyzing how different dimensions of scientific reasoning operate in this conceptual domain. Therefore, a focused investigation grounded in Lawson's theoretical framework is needed to describe how students apply scientific reasoning when engaging with temperature and heat concepts.

In this study, Lawson's scientific reasoning framework is used as the theoretical foundation for measuring and interpreting students' reasoning in the context of temperature and heat. By aligning each reasoning indicator with core thermal concepts, this research positions scientific reasoning not merely as a general cognitive skill, but as a domain-specific process that supports meaningful physics learning. This theoretical perspective provides the basis for analyzing students' reasoning profiles and for informing future instructional designs that aim to strengthen scientific thinking in physics education.

3. Method

3.1 Research Design

This study employed a quantitative descriptive research design to obtain an empirical profile of students' scientific reasoning skills in the context of temperature and heat. The design was intended to describe how students apply different forms of scientific reasoning when dealing with thermal concepts, rather than to test the effectiveness of a particular instructional intervention (Creswell, 2019). The assessment was constructed based on Lawson's six scientific reasoning indicators, each operationalized within temperature and heat phenomena such as heat transfer, thermal equilibrium, and phase change. This design ensures that students' reasoning is examined through meaningful physics contexts rather than decontextualized logic tasks.

3.2 Participants and Ethical Considerations

The participants were 36 twelfth-grade students from one public senior high school in Tasikmalaya, Indonesia. The class was selected using purposive sampling, as the students had completed formal instruction on temperature and heat, ensuring adequate conceptual exposure. Prior to data collection, ethical approval was obtained from the school, and permission was granted by the physics teacher and school administration. All students participated voluntarily, and informed consent was obtained. Students were informed that the data would be used only for research purposes, their identities would remain anonymous, and their responses would not affect academic grading.

3.3 Data Collection Procedure

Data were collected during the first semester of the 2025/2026 academic year. The scientific reasoning test was administered in a regular physics class session after the topic of temperature and heat had been completed. Students were given sufficient time to answer all items independently. The researcher and the physics teacher supervised the session to ensure that the test was completed under standard and fair conditions.

3.4 Instrument Development

The scientific reasoning instrument consisted of six two-tier multiple-choice items, with each item representing one of Lawson's six scientific reasoning indicators. Each item was developed within the context of temperature and heat so that students' reasoning was assessed through meaningful physics situations rather than abstract logical problems. The conservation reasoning item measured students' understanding of energy conservation in heat transfer processes. The proportional reasoning item examined the relationship between the amount of heat and temperature change. The control of variables item assessed students' ability to identify and isolate relevant variables in thermal processes such as melting or heating. The probability reasoning item evaluated students' ability to predict the likelihood of phase changes under given thermal conditions. The correlation reasoning item measured students' ability to identify relationships among thermal variables such as temperature, mass, and heat energy. The hypothetical-deductive reasoning item assessed students' ability to formulate and test predictions related to thermal equilibrium and heat flow.

All items were constructed in a two-tier multiple-choice format, where the first tier measured students' conceptual answers and the second tier probed the scientific reasoning underlying their choices.

This format allows the instrument to distinguish between correct answers obtained by guessing and those produced through valid scientific reasoning. The instrument blueprint is presented in Table 1, which shows the alignment between each Lawson indicator, the measured reasoning skill, and the corresponding temperature and heat context.

Table 1. *Instrument Blueprint*

No	Indicator	Measured Skill	Temperature and Heat Context
1	Conservation reasoning	Understanding energy conservation	Heating objects with different heat capacities
2	Proportional reasoning	Relating heat to temperature change	Heating water
3	Control of variables	Identifying variables in phase change	Melting ice
4	Probability reasoning	Predicting likelihood of phase change	Ice at 0°C
5	Correlation reasoning	Identifying relationships between heat and physical change	Drying materials
6	Hypothetical-deductive reasoning	Predicting outcomes based on hypotheses	Thermal equilibrium

Before being administered, the instrument was subjected to content and construct validation by physics education experts to ensure that each item accurately represented the corresponding scientific reasoning indicator and was conceptually aligned with temperature and heat concepts. The experts evaluated the clarity, relevance, and scientific accuracy of each item, and revisions were made based on their feedback. The validated instrument was then tested empirically, and its reliability was calculated using Cronbach's Alpha, yielding a coefficient of 0.86, which indicates high internal consistency. This result confirms that the six items consistently measure scientific reasoning as a unified construct.

3.5 Data Analysis Technique

Students' responses were scored using a two-tier rubric shown in Table 2.

Table 2. *Scoring Guidelines for the Two-Tier Multiple-Choice Instrument*

Answer (Tier 1)	Reasoning (Tier 2)	Skor	Assesment Criteria
Correct	Correct	3	The answer is correct and conceptually appropriate; the reasoning is logical and aligned with the indicators of scientific reasoning skills.
Correct	Incorrect	2	The answer is correct, but the reasoning is incorrect or illogical.
Incorrect	Correct	1	The answer is incorrect, but the reasoning is correct.
Incorrect	Incorrect	0	Both the answer and the reasoning are incorrect or not aligned with the concept.

The final score of students' scientific reasoning skills is calculated using the following formula (Purwanto, 2014)

$$x = \frac{R}{SM} \times 100$$

where x indicates the achievement score of scientific reasoning skills, R is the score obtained by students, and SM is the maximum test score.

The categories of scientific reasoning skills percentage levels according to (Arikunto, 2019) are presented in Table 3.

Table 3. *Scientific Reasoning Skills Categories*

Average Score	Category
81 - 100	Very High
61 - 80	High
41 - 60	Modetare
21 - 40	Low
0 - 20	Very Low

3.6 Role of the Method in This Study

This methodological design allows the study to function as a diagnostic mapping of students' scientific reasoning on temperature and heat. Rather than testing instructional effectiveness, the method provides an empirical basis for identifying reasoning strengths and weaknesses that can guide future instructional design and intervention studies.

4. Result

4.1 Overview of Students' Scientific Reasoning Skills

The scientific reasoning test in this study was designed to capture students' ability to apply different forms of scientific reasoning when dealing with the conceptual structure of temperature and heat. Each test item represented one of Lawson's six reasoning indicators and was embedded in thermal contexts such as heat transfer, temperature change, phase transition, and thermal equilibrium. This design required students not only to recall formulas but also to interpret physical situations, identify relevant variables, and justify their answers logically through the second tier of each item. As a result, the test imposed a relatively high cognitive demand, particularly on students' ability to connect conceptual understanding with formal reasoning.

The descriptive statistics obtained from the test (minimum score = 0, maximum score = 17, mean = 9.33, and standard deviation = 1.16) indicate that many students encountered difficulties when they were required to justify their answers using scientific reasoning. The relatively low mean score suggests that although some students were able to select correct answers at the first tier, they often struggled to provide appropriate scientific explanations at the second tier. This pattern implies that students' procedural or intuitive understanding of thermal phenomena was not always accompanied by well-developed conceptual and logical reasoning.

From the perspective of the assessment design, these results reveal that the two-tier format successfully differentiated between superficial correctness and genuine scientific reasoning. Students who lacked strong conceptual reasoning tended to fail at the justification level, even when they selected the correct option. This indicates that the instrument was sensitive to variations in students' reasoning quality rather than merely measuring factual knowledge. Consequently, the results obtained through this design provide a meaningful profile of how students reason about temperature and heat, which is essential for identifying specific weaknesses in their scientific reasoning skills.

4.2 Analysis of Scientific Reasoning Indicators

Students' scientific reasoning skills were further analyzed based on the six indicators proposed by Lawson: conservation reasoning, proportional reasoning, control of variables, probability reasoning, correlation reasoning, and hypothetical-deductive reasoning. The results of this analysis are presented in Table 3, which summarizes the mean score, percentage, and category for each indicator. SD indicates the standard deviation.

Table 3. *Students' Scientific Reasoning Skills by Indicator*

No	Indicator	Ave. Score	Score	SD	Interpretation
1	Conservation Reasoning	1.50	50	1.11	Moderate
2	Proportional Reasoning	1.64	54.63	1.33	Moderate
3	Control of Variables	1.78	59.26	1.24	Moderate
4	Probability Reasoning	1.67	55.56	1.17	Moderate
5	Correlation Reasoning	1.36	45.37	0.93	Moderate
6	Hypothetical-Deductive Reasoning	1.39	46.30	1.18	Moderate
	Conclusion		51.85	1.16	Moderate

All six indicators fall within the moderate category, indicating that students possess a basic level of scientific reasoning across different dimensions, but none of the reasoning skills has developed to a high level. This pattern suggests that students are able to engage with scientific tasks at a surface or intermediate level, yet they have not fully mastered the deeper forms of reasoning required for conceptual and analytical understanding in physics. The relatively uniform distribution of scores across indicators can be explained by the nature of classroom learning and assessment practices. Physics instruction tends to emphasize procedural problem-solving and direct application of formulas, which supports students' performance in more concrete forms of reasoning such as conservation and control of variables. This is reflected in the higher scores for these indicators, especially control of variables (59.26%), which is commonly trained through experiments and worked examples.

In contrast, correlation reasoning (45.37%) and hypothetical-deductive reasoning (46.30%) show the lowest achievement. These indicators require students to engage in abstract, relational, and inferential thinking, such as identifying relationships between multiple thermal variables or predicting outcomes based on hypothetical conditions. Such forms of reasoning are rarely trained explicitly in routine classroom practice, which explains why students struggle more with these indicators even though they have learned the relevant concepts. The moderate level across all indicators also reflects the two-tier assessment format. Many students may select a correct option in Tier 1 but fail to justify it correctly in Tier 2, resulting in partial scores that place their performance in the moderate range. Therefore, the results in Table 3 provide a comprehensive and sufficient representation of students' scientific reasoning profiles, making a separate graphical visualization unnecessary.

5. Discussion

To enhance clarity and readability, the discussion is organized into three subsections: interpretation of the findings, implications and directions for future research, and study limitations.

5.1. Interpretation of the Findings

The findings of this study indicate that students' scientific reasoning skills on the topic of temperature and heat have not yet developed to an optimal level. Although students have completed formal instruction on this topic, their reasoning remains largely procedural rather than conceptual. This pattern suggests that physics learning in the observed school has not sufficiently fostered the habit of reasoning scientifically, where students are expected to analyze relationships, justify conclusions, and connect empirical evidence with theoretical principles.

This condition can be partly explained by the instructional background of the participants. Based on information obtained from the school context, physics teaching is predominantly oriented toward completing syllabus targets and solving standard numerical problems. Students are trained to follow formulas and apply algorithmic steps, but they are rarely engaged in activities that require them to design investigations, test hypotheses, or reflect on the meaning of physical relationships. As a result, students tend to rely on memorized procedures rather than on scientific reasoning when facing physics problems.

The difficulty of the temperature and heat topic itself also contributes to this pattern. Thermal concepts such as heat transfer, thermal equilibrium, and energy transformation are abstract and cannot be observed directly. Understanding these concepts requires students to infer invisible processes and relate multiple variables logically. When learning is dominated by formula-based instruction without sufficient conceptual exploration, students may be able to perform calculations but fail to understand how and why physical phenomena occur. This explains why students' reasoning tends to remain fragmented and superficial.

This finding is consistent with studies conducted in Indonesian secondary schools, which report that students often struggle to apply scientific reasoning when dealing with physics concepts (Mayasyafira et al., 2025; Yusa et al., 2022). However, other studies conducted in learning environments that implement inquiry-based, problem-based, or reasoning-oriented instruction have shown that students can develop stronger scientific reasoning skills (Fitri et al., 2025; Ningrum et al., 2024). This contrast suggests that scientific reasoning is not a fixed trait of students, but rather is highly influenced by instructional design and learning opportunities.

Therefore, the present study highlights an important educational implication: students in this school possess the potential to reason scientifically, but the learning environment has not yet provided sufficient opportunities to cultivate this potential. When physics learning emphasizes explanation, investigation, and evidence-based argumentation, students' reasoning skills can develop beyond procedural competence toward more mature scientific thinking. Thus, the results of this study provide empirical support for the need to shift physics instruction from formula-centered teaching to reasoning-centered learning, particularly in abstract topics such as temperature and heat.

5.2. Implications and Directions for Future Research

Based on the findings of this study, several important implications for physics learning can be identified. The low achievement of students in abstract and deductive reasoning, particularly in correlation reasoning and hypothetical-deductive reasoning, indicates that current physics instruction has not sufficiently trained students to analyze relationships among variables and to construct evidence-based explanations when learning about temperature and heat. This supports Lawson (2004) view that formal scientific reasoning develops through systematic experience in reasoning, testing, and reflecting on evidence, rather than through memorization of formulas alone.

The use of the two-tier multiple-choice scientific reasoning test in this study also provides a practical contribution to physics education. As suggested by Treagust (1988), two-tier tests can reveal not only whether students choose correct answers but also whether their underlying reasoning is scientifically valid. Therefore, this type of instrument can be used as a diagnostic and formative assessment tool in physics classrooms to identify students' reasoning patterns on temperature and heat as well as on other physics topics, such as mechanics or electricity, so that teachers can design appropriate instructional follow-up.

Furthermore, the results of this study show that students struggle most when they are required to interpret data, identify correlations, and formulate or test hypotheses in thermal contexts. This implies that physics learning should place greater emphasis on activities that involve problem exploration, experimental investigation, and justification of conclusions based on evidence, rather than focusing mainly on numerical calculations. In line with Fitri et al. (2025) and Taniatara & Wulandari (2024), learning environments that provide opportunities for open-ended problem solving, idea generation, and reflective thinking are more likely to support the development of higher-level scientific reasoning.

In this pedagogical context, the Creative Problem Solving (CPS) model becomes a relevant alternative, because its stages of problem identification, idea exploration, evaluation, and decision making correspond closely to the processes of hypothesis formation, testing, and deductive reasoning in science (Lawson, 2004). The reasoning profile obtained in this study can therefore serve as an empirical basis for designing CPS-based or inquiry-oriented physics instruction that specifically targets weaknesses in abstract and deductive reasoning on temperature and heat.

For future research, the descriptive profile generated in this study can be used as a baseline for examining the effectiveness of different instructional models in improving students' scientific reasoning skills. Subsequent studies are encouraged to employ experimental or quasi-experimental designs to investigate how approaches such as CPS, inquiry-based learning, or problem-based learning influence students' reasoning across Lawson's six indicators, and to involve larger and more diverse samples in order to strengthen the generalizability of the findings.

5.3. Limitations

Despite the meaningful insights generated, several limitations of this study should be acknowledged to ensure an appropriate interpretation of the findings. This study involved a relatively small number of participants and was conducted in only one public senior high school. Therefore, the extent to which the findings can be generalized to broader student populations, different regions, or different school contexts remains limited. Such constraints are common in educational research and may affect the external validity of the results (Jogdand & Naqvi, 2023). In addition, the instrument used in this study focused exclusively on the cognitive dimension of scientific reasoning skills. It did not capture affective, motivational, or dispositional aspects of scientific thinking, which have been shown to also influence students' reasoning performance (García-carmona, 2025). As a result, the findings provide only a partial picture of students' scientific reasoning profiles.

Furthermore, this study did not include demographic or background variables such as gender, prior academic achievement, or learning experiences. Previous research suggests that such characteristics may contribute to differences in students' scientific reasoning abilities (Schlatter, 2020). The absence of these variables limits the ability to examine how individual differences may have influenced the observed reasoning patterns.

5.4. Instructional Recommendations

Overall, the findings of this study indicate that senior high school students' scientific reasoning skills, particularly in abstract and deductive components such as correlation reasoning and hypothetical-deductive reasoning, still require substantial improvement. This condition suggests that current physics learning practices have not yet sufficiently supported the development of higher-order scientific thinking.

Therefore, future instructional designs should move beyond an emphasis on formula application and procedural problem-solving toward learning environments that explicitly engage students in observing phenomena, analyzing evidence, and drawing data-based conclusions.

Within this context, learning strategies that emphasize inquiry, problem exploration, and reflective reasoning become highly relevant. One promising direction for future research is the implementation of learning models that systematically guide students through processes of problem identification, idea generation, evaluation, and justification. In particular, the Creative Problem Solving (CPS) model offers a theoretically grounded framework that aligns well with the reasoning demands identified in this study. Although CPS was not implemented in the present research, its structure provides a strong basis for future intervention studies aimed at improving students' scientific reasoning in the context of temperature and heat and other physics topics.

6. Conclusion

This study concludes that the scientific reasoning skills of senior high school students on the topic of temperature and heat are at a moderate level, with notable weaknesses in correlation reasoning and hypothetical-deductive reasoning. Students show stronger performance in concrete and procedural aspects of thermal phenomena than in abstract and deductive tasks that require explaining variable relationships and predicting outcomes based on hypotheses. This profile indicates that current physics instruction has not yet sufficiently supported the development of higher-order scientific reasoning. Therefore, physics learning should be designed to more explicitly engage students in analyzing data, comparing variables, formulating hypotheses, and justifying conclusions through evidence-based reasoning, particularly in the context of abstract topics such as temperature and heat.

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Authors Contribution

Rifa Anjiana: Conceptualization, Methodology, Instrument development, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Endang Surahman:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Rahmat Rizal:** Methodology, Data interpretation, Writing – review & editing, Supervision. **Diana Hernawati:** Writing – review & editing. **Liah Badriah:** Writing – review & editing.

Ethical statement

This study was conducted in regular classroom teaching settings and is classified as minimal-risk educational research under the institutional guidelines of Universitas Siliwangi, Indonesia. Permission to conduct the study and to collect data in the participating school was obtained through an official research permission letter from the relevant institutional authorities and the school administration.

Participation in the study was entirely voluntary. All students were informed about the purpose of the research, the procedures involved, and their right to withdraw at any time without any academic or personal consequences. Written informed consent was obtained from all participants, and additional permission was secured from teachers and school authorities as required. No sensitive personal data were collected, and all student responses were anonymized and used solely for research purposes. All procedures involving human participants were conducted in accordance with generally accepted ethical standards for educational research and the principles of the Declaration of Helsinki, and informed consent was obtained from all participants.

Declaration of AI use

The authors used ChatGPT (OpenAI) to assist in improving sentence clarity, coherence, and academic readability of the original manuscript draft. All AI-assisted outputs were carefully reviewed, edited, and validated by the authors. The authors take full responsibility for the originality, accuracy, and integrity of the final manuscript. No generative AI tools were used for data analysis or the creation of figures.

Conflict of Interest

The authors declare that there is no conflict of interest, either financial or non-financial, that could be perceived as influencing the work reported in this manuscript. All authors have reviewed and approved this statement.

Supplementary Materials and Data Availability

No public repository is currently available for the dataset used in this study. However, the research instrument (two-tier multiple-choice test), scoring guidelines, and summarized data supporting the findings of this study can be obtained from the corresponding author upon reasonable request. Any data shared will be anonymized and provided in accordance with ethical standards and institutional regulations.

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