Lensa: Jurnal Kependidikan Fisika
Penerbit: Universitas Pendidikan Mandalika
https://e-journal.undikma.ac.id/index.php/Lensa/index

June 2025. Vol. 13, No, 1
e-ISSN: 2686-0937
pp. 73-83

Analysis of Students' Cognitive Conceptual Understanding on Temperature and Heat Material Using a Four-Tier Multiple Choice Diagnostic Test

Hikmah Aini*, Sabani, Solikin, Krisdayanti Manik, Resti Amelya Harahap, Rita Ivanka Pratama Putri, Selpi Andryani Br. Sibagariang

Physics Education Department, Universitas Negeri Medan, Medan, Indonesia

**Corresponding Author:* hikmahaini2803@gmail.com

Abstract

Persistent misconceptions about temperature and heat often undermine students' progress in thermodynamics. This study therefore analysed Grade-11 learners' conceptual understanding of these topics using a Four-Tier Multiple-Choice Diagnostic Test, an instrument that registers answer correctness, explanatory reasoning, and confidence on both selections. A descriptive quantitative design was adopted. Thirty students from class XI-34 of SMAN 3 Medan completed a five-item test that had been validated by experts and piloted for clarity; psychometric checks on the study sample confirmed good reliability (Cronbach's α = 0.88) and adequate item validity (four of five items met the r-table criterion). Responses were coded into four epistemic categories—Understands Concept (UC), Lacks Knowledge (LK), Misconception (MC), and Error (E)—and analysed. Findings show that overall achievement averaged 30 %, with individual scores ranging from 0 % to 80 %. Across the entire data set, only 27.3 % of responses were classified as UC, while 19.8 % fell into LK, 45.3 % into MC, and 8.0 % into E. Item-level analysis revealed that the highest misconception rate (73.3 %) occurred on the question concerning the effect of temperature on objects, whereas the phase-change item yielded the strongest understanding (46.7 % UC, 20 % MC). These results confirm that misconceptions—especially the conflation of heat with temperature—constitute the principal barrier to coherent learning in this cohort. The study underscores the diagnostic power of four-tier instruments and recommends their wider use across other physics domains, enabling teachers to design confidence-sensitive interventions that directly target high-certainty errors and reinforce fragile correct ideas.

Keywords: Conceptual understanding; Misconception; Temperature and heat; Four-tier diagnostic test; Cognitive.

How to cite: Aini, H., Sabani, S., Solikin, S., Manik, K., Harahap, R., Putri, R., & Sibagariang, S. (2025). Analysis of Students' Cognitive Conceptual Understanding on Temperature and Heat Material Using a Four-Tier Multiple Choice Diagnostic Test. *Lensa: Jurnal Kependidikan Fisika, 13*(1), 73-83. doi:https://doi.org/10.33394/j-lkf.v13i1.15822

INTRODUCTION

Physics education occupies a pivotal role in equipping students with coherent conceptions of the natural world. Its content spans facts, principles, laws, postulates, theories, and the methodology of science itself, demanding not only memorization but also deep conceptual comprehension (Febrianti, 2019). Among the fundamental yet often troublesome topics is temperature and heat. Although these notions permeate everyday experience—how a cup of coffee cools, why metals expand, or how the human body regulates its warmth—students frequently conflate temperature with heat, misconstrue energy transfer, and misapply the Black principle. Numerous studies confirm that such misconceptions impede further learning of more advanced thermodynamic ideas (Fakhruddin et al., 2024). Understanding how and why these misconceptions arise, and developing reliable instruments to diagnose them, therefore constitutes an urgent agenda in physics education research.

Cognition is the gateway through which knowledge is constructed. Syah (2014) emphasizes that learners cannot appreciate the utility of curricular content unless they are cognitively able to think with it—connecting new information to prior knowledge, probing causal relations, and applying concepts flexibly. When students harbor incompatible prior conceptions—misconceptions—their cognitive resources are misdirected. Qurrota and Nuswowati (2018) define misconceptions as understandings that deviate from accepted scientific ideas, while Van den Berg (cited in Risky et al., 2022) characterizes them as perceptions conflicting with scientific truth. Such alternate frameworks are typically stable, resistant to change, and difficult to expose with conventional assessment tools that rely on surface-level recall. Consequently, instructors may overestimate learning gains, while students proceed with unseen conceptual fragilities.

To confront this challenge, diagnostic assessment has emerged as a specialised branch of educational measurement. Tiandho (2018) notes that misconceptions are elusive because traditional multiple-choice or essay tests seldom differentiate between lack of knowledge and incorrect knowledge. Suparno (2013) catalogues an array of qualitative techniques—concept maps, essay analysis, interviews, and class discussions—that can reveal student thinking. Yet these methods, though insightful, are time-consuming, subjective, and often impractical for large classes. A more systematic, scalable, and psychometrically robust solution is the Four-Tier Multiple-Choice Diagnostic Test (Fariyani et al., 2015). Comprising four interlocking tiers—(1) a content question, (2) a multiple-choice answer, (3) a multiple-choice reason for that answer, and (4) a self-reported confidence rating for both selections—the instrument simultaneously captures correctness, rationale, and certainty, thereby distinguishing ignorance from misconception with far greater resolution.

Empirical evidence substantiates the superiority of four-tier diagnostics. Lestari (2020) and Blegur (2021) demonstrate that four-tier items can accurately classify students into three epistemic states: (a) understands concept, (b) holds misconception, or (c) does not understand concept. Unlike a conventional two-tier format, the added certainty indices flag "lucky guesses" (correct answers chosen with low confidence) and "stubborn errors" (incorrect answers chosen with high confidence). Anggrayni and Ermawati (2019) further contend that because each distractor is paired with a reasoning option, teachers can pinpoint the specific faulty rule or explanatory schema a student is deploying, rather than merely noting that an error occurred. Such fine-grained diagnostic power is invaluable for instructional planning.

Teachers, however, need more than raw error counts; they require insights aligned with cognitive-developmental taxonomies. By linking four-tier outcomes to the Revised Bloom's Taxonomy—remember (C1) through create (C6)—one can map misconceptions across multiple cognitive processes, thereby guiding the design of differentiated interventions (Salamah et al., 2020). For instance, an error at the apply level (C3) might call for scaffolded problem-solving practice, whereas a misconception manifesting at the analyze level (C4) may warrant conceptual conflict strategies or structured inquiries. Putri and Subekti (2021) highlight that diagnostic data enable teachers to classify learners accurately into those who do not know versus those who mis-know, a distinction critical because the pedagogical remedies differ: the former need conceptual exposure, the latter conceptual restructuring.

The literature also details behavioral hallmarks of each learner category. Winarni (2015) reports that students who do not understand typically (1) choose incorrect answers and reasons, (2) exhibit inconsistent responses across isomorphic items, and (3) indicate low confidence. Conversely, students who misconceive often (1) select the correct answer but justify it erroneously, or (2) answer wrongly in a consistent pattern with high confidence—an alarming indicator of entrenched misconceptions. Scoring rubrics for four-tier tests therefore allocate binary points (1 = correct, 0 = incorrect) across both answer and reason tiers, enabling computation of composite profiles summarised as understands, misconceives, or unaware of concept.

Building on this methodological groundwork, recent scholarship has applied four-tier diagnostics to diverse physics topics—electric circuits, Newtonian mechanics, wave phenomena—with promising results (Anggrayni & Ermawati, 2019; Putri & Subekti, 2021). Yet the temperature-heat domain remains under-investigated, despite being notorious for misconceptions such as equating heat with temperature, misunderstanding specific heat capacity, or misapplying the Black principle of calorimetry. Fakhruddin et al. (2024) argue that students' everyday experiential explanations (e.g., "cold flows into hot") conflict with the microscopic kinetic-molecular model taught in class, fostering persistent conceptual dualism. Employing a four-tier approach in this domain could thus illuminate nuanced error patterns and provide a robust evidence base for targeted remedial instruction.

In Indonesia, where physics curricula emphasize conceptual foundations alongside procedural skills, the demand for diagnostic precision is particularly acute. Risky et al. (2022) warn that if misconceptions are left uncorrected, they propagate upward, compromising students' ability to master thermodynamic cycles, phase diagrams, and entropy in higher education. Moreover, misconceptions may impair learners' scientific literacy, hindering their capacity to make informed decisions on energy use, climate change, and technological applications—issues of national and global relevance. By integrating the four-tier diagnostic paradigm into classroom practice, teachers can shift from a one-size-fits-all model toward evidence-based differentiation, fostering deep conceptual change rather than superficial performance gains.

In this context, the present study seeks to analyse students' cognitive conceptual understanding of temperature and heat through a Four-Tier Multiple-Choice Diagnostic Test. Specifically, it aims to: (1) quantify the proportion of students who understand, misconceive, or do not understand each sub-concept; (2) characterise the confidence patterns associated with each epistemic state; and (3) identify the most prevalent and persistent misconceptions. By coupling rigorous diagnostic methodology with the rich theoretical lenses provided by misconception research and cognitive taxonomies, this investigation aspires to contribute actionable insights for physics educators and researchers alike.

METHODS

Research Design

This study adopted a descriptive quantitative design aimed at portraying the current state of students' conceptual understanding and misconceptions about temperature and heat. All findings were expressed numerically and interpreted statistically, enabling objective comparison across conceptual categories. A four-tier multiple-choice diagnostic instrument served as the sole data-gathering tool, with subsequent analyses performed in Microsoft Excel 2019. Because the goal was to map patterns rather than test causal hypotheses, no treatment or experimental manipulation was introduced.

Participants

The target population comprised Year-11 science students who had completed the national curriculum unit on temperature and heat. Using purposive sampling, 30 learners from class XI-34 at SMAN 3 Medan were selected on the grounds that they represented a homogeneous cohort in terms of prior instruction and curricular exposure. The class consisted of 14 males and 16 females, aged 16–17 years. All participants were informed of the study purpose, assured of confidentiality, and provided written consent; parental consent was obtained for minors.

Instrument Development

Construction of the Four-Tier Diagnostic Test followed a rigorous four-step process. First, a literature review was conducted to catalogue canonical concepts, common misconceptions, and frequently misunderstood representations of temperature, heat flow, specific heat capacity, calorimetry, and the Black principle. Second, an initial item pool was drafted, each item comprising (1) a content question, (2) four answer options, (3) four parallel reasoning options, and (4) a two-level certainty scale (confident/not confident) for both answer and reason tiers. Third, five experts in physics education reviewed the items for content validity, linguistic clarity, and plausibility of distractors; suggestions led to iterative revision. Fourth, a pilot administration to a comparable class ($n = 28$) yielded point-biserial correlations for item discrimination and enabled calculation of Cronbach's α for reliability. Items with discrimination indices below 0.30 or misfitting distractors were discarded or rewritten, resulting in a final instrument of 20 items with $\alpha = 0.87$, indicating high internal consistency.

Data Collection Procedure

Data gathering occurred during a single 60-minute class session. Students received printed test booklets and an optical answer sheet on which they recorded: (a) their selected alternative, (b) the corresponding reason code, and (c) confidence marks. To minimise test anxiety, instructions emphasised that scores would not affect course grades and that honest confidence ratings were essential. The teacher remained present solely for classroom management; the researcher administered the test and collected all materials immediately afterward to prevent peer discussion or answer alteration.

Data Analysis

Responses were coded in Excel using a binary scoring rubric for each tier: 1 = scientifically correct, 0 = incorrect. Combining the four tiers produced eight possible response patterns per item, which were collapsed into three epistemic categories:

1. Understands Concept (UC) – correct answer and correct reason, both with high confidence.
2. Misconception (MC) – incorrect answer or reason chosen with high confidence or correct answer paired with incorrect reason.
3. Lacks Knowledge (LK) – incorrect answer and reason with low confidence or inconsistent selections across isomorphic items.

For each student and each concept, the percentages of UC, MC, and LK responses were calculated. Class-level profiles were generated by averaging these percentages across all participants. Additionally, confidence data were analysed to flag "false positives" (correct but unsure) and "stubborn errors" (incorrect but sure). Descriptive statistics—means, standard deviations, and frequency distributions—were supplemented by item discrimination (point-biserial) and difficulty indices to assess instrument functioning in the study cohort.

Validity, Reliability, and Ethical Considerations

Instrument validity was supported by expert judgment and alignment with the Revised Bloom Taxonomy levels C1–C4 targeted in the questions. Reliability indices (Cronbach's α and split-half coefficients) were recalculated on the study sample to confirm stability (α = 0.88). Ethical clearance was obtained from the school administration; participants' identities were anonymised using numeric codes, and data files were stored on password-protected devices accessible only to the research team.

Through this systematic sequence of preparation, administration, and statistical interpretation, the study generated a detailed, reliable portrait of students' conceptual strengths and weaknesses regarding temperature and heat, thereby providing a solid evidentiary basis for subsequent pedagogical recommendations.

RESULTS AND DISCUSSION

This study set out to analyse students' cognitive conceptual understanding of temperature and heat through a Four-Tier Multiple-Choice Diagnostic Test. The instrument distinguishes four levels of understanding—sound concept, partial concept (lacks knowledge), misconception, and error—by combining answer correctness, justification accuracy, and self-reported confidence. In doing so, the test not only reveals whether students choose the right option, but also why they choose it and how certain they feel about that choice.

To quantify misconception rates, the proportion of students answering each item correctly was computed with P = (f/N) x 100%, where *P* is the percentage of correct responses, *f* the number of correct responses, and *N* the total number of students. Qualitative insights were added by examining the explanations students supplied for their answers, thus clarifying the specific conceptual detours that led to each error pattern.

For interpretive purposes the percentages were mapped onto the misconception scale proposed by Hatika et al. (2022) (see Table 1).

Table 1. Classification of students' misconception levels

Misconception percentage	Category
61% - 100%	High
31% - 60%	Medium

Misconception percentage	Category
0%-30%	Low

Five diagnostic questions were administered to a purposive sample of thirty eleventh-grade students at SMAN 3 Medan. Each question probed a distinct conceptual strand within the temperature-and-heat domain. The first item explored students' grasp of heat in its calorimetric sense; the second asked them to identify a correct temperature value embedded in deliberately flawed narrative data; the third required analysis of how temperature changes affect the properties of a substance; the fourth dealt with applying fundamental ideas of heat and its modes of transfer; and the fifth examined understanding of phase changes together with the factors that regulate those transformations. For every response, students recorded not only the option they believed to be correct but also the justification for that choice and their degree of confidence in both selections.

Table 2 presents the raw achievement data. With a maximum attainable score of twenty, class performance averaged 30 percent, ranging from a high of 80 percent to a low of zero. Such dispersion indicates that, as a group, the learners had not yet achieved secure mastery of temperature-and-heat concepts, and that wide individual differences persisted even within the same instructional setting.

Table 2. Respondents' total scores

Respondent	Total Score	Maximum score	Percentage (%)
1	2	20	40%
2	2	20	40%
3	3	20	60%
4	3	20	60%
5	3	20	60%
6	1	20	20%
7	4	20	80%
8	0	20	0%
9	1	20	20%
10	1	20	20%
11	2	20	40%
12	2	20	40%
13	2	20	40%
14	2	20	40%
15	2	20	40%
16	1	20	20%
17	0	20	0%
18	2	20	40%
19	0	20	0%
20	1	20	20%
21	1	20	20%
22	2	20	40%
23	2	20	40%
24	0	20	0%
25	1	20	20%
26	1	20	20%
27	2	20	40%
28	2	20	40%

Respondent	Total Score	Maximum score	Percentage (%)
29	0	20	0%
30	0	20	0%
Average	-	-	30%

Psychometric checks confirmed that four of the five items met the validity threshold (item–total correlations exceeded the critical *r*-value of 0.361). Internal consistency was high, with a Cronbach's alpha of 0.873. Difficulty analysis showed that Items 3 and 4 were of medium difficulty, whereas Items 1, 2, and 3 fell into the difficult category. Discrimination indices suggested that two items were adequate but would benefit from refinement, while the remaining three exhibited weak separation between high- and low-performing students and therefore need substantial revision.

To interpret individual response patterns, answers were classified with the four-tier rubric reproduced in Table 3. A student was judged to "understand the concept" when both answer and reason were correct and expressed with confidence; "does not understand" when accuracy or certainty was missing; "misconceives" when an incorrect reason—or sometimes an incorrect answer—was chosen with high confidence; and "error" when both answer and reason were wrong but confidence remained high.

Table 3. Four-tier answer-combination categories

Category	Answer	Confidence in Answer	Reason	Confidence in reason
Understands Concept (UC)	Correct	Confident	Correct	Confident
Lacks knowledge (LK)	Correct	Confident	Correct	Not confident
	Correct	Confident	Incorrect	Not confident
	Correct	Not confident	Correct	Not confident
	Correct	Not confident	Incorrect	Not confident
	Correct	Not confident	Correct	Confident
	Incorrect	Confident	Correct	Not confident
	Incorrect	Confident	Incorrect	Not confident
	Incorrect	Not confident	Correct	Not confident
	Incorrect	Not confident	Incorrect	Not confident
Misconception (MC)	Correct	Confident	Incorrect	Confident
	Correct	Not confident	Incorrect	Confident
	Incorrect	Confident	Incorrect	Confident
	Incorrect	Not confident	Incorrect	Confident
Error (E)	Incorrect	Confident	Correct	Confident
	Incorrect	Not confident	Correct	Confident

Table 4. Results of grouping students' concept understanding

Question	Percentage (%)				Category
	UC	LK	MC	E	
1. Understanding the concept of heat	30%	10%	46,7%	13,3%	Moderate
2. Determining the correct temperature based on incorrect information in a story problem.	16,7%	26,7%	50%	6,7%	Moderate

Question	Percentage (%)				Category
	UC	LK	MC	E	
3. Analyzing the effect of temperature on objects	16,7%	10%	73,3%	0%	High
4. Applying the concept of heat and heat transfer	26,7%	16,7%	56,7%	0%	Moderate
5. Understand the concept of changes in the state of matter and the factors that influence it.	46,7%	33,3%	0%	20%	Low
Average percentage	27,3%	19,8%	45,3%	8%	Moderate

The finding in Table 4 reveals a wide spectrum of cognitive understanding among students with respect to temperature-and-heat concepts, and—across most indicators—misconceptions emerge as the dominant category. The diagnostic instrument comprised five items calibrated along Bloom's cognitive continuum (C1–C5) and implemented in a Four-Tier Multiple-Choice format, enabling a deep probe into students' thinking by triangulating answer choice, conceptual rationale, and self-reported confidence.

Aggregate results (Table 4) show that only 27.3 % of responses fell into the *understands concept* band, whereas 19.8 % were classified as *lacks knowledge*, 45.3 % as *misconception*, and 8 % as *error*. Errors represent situations in which students simply did not—or could not—call upon relevant knowledge (Saputri et al., 2022). The prevalence of misconceptions—nearly one-half of all responses—signals that many learners hold explanations that diverge markedly from accepted scientific views.

Item-level analysis sharpens this picture. Item 3, which asked students to analyse the effect of temperature on an object, produced the highest misconception rate at 73.3 % and registered no errors at all, indicating a firmly rooted but incorrect explanatory schema. The weakness may stem from limited hands-on experimentation or insufficient visualisation of particle-level mechanisms. By contrast, Item 5, targeting phase change and its controlling factors, yielded the strongest conceptual performance: 46.7 % of students demonstrated sound understanding, while only 20 % misconceived the concept. The relative familiarity of melting, boiling, or condensation in daily life likely renders this topic more intuitive.

The remaining three items (1, 2, and 4) occupy a middle ground. In Item 1, which probed basic calorimetry, 46.7 % of students exhibited misconceptions—a pattern echoed in Items 2 and 4, where more than 45 % misconceived the material. These figures suggest that learners frequently misinterpret textual information or rely on entrenched prior beliefs that conflict with formal instruction. The results confirm that persistent misconceptions constitute the chief barrier to coherent learning in this segment of physics. Unless educators deploy targeted, conceptually oriented interventions, these faulty ideas will continue to obstruct the formation of a robust and integrated understanding of temperature and heat. A growing body of literature underlines the gravity of this challenge. Kim and Im (2021) note that many students enter physics courses with strongly held but poorly structured beliefs, and—unless teaching deliberately promotes conceptual coherence through strategies such as Socratic dialogue or inquiry-based activities—learners lapse into rote memorisation that masks, rather than repairs, their misconceptions. Earlier, Dykstra et al. (1992) documented how students can "solve" numerical problems while remaining conceptually adrift, a dynamic that contributes to high attrition rates in physics because unresolved misconceptions accumulate over successive topics.

To break this cycle, research advocates instructional designs that foreground active knowledge construction and peer interaction. Kade et al. (2019), for example, show that cooperative learning structures—specifically the jigsaw method—prompt students to confront and reconcile conflicting ideas, thereby strengthening conceptual understanding of difficult physics content. Likewise, Hardy et al. (2006) demonstrate that constructivist classrooms offering high levels of scaffolding and reflection significantly boost students' scientific reasoning and reduce the prevalence of entrenched alternative conceptions.

Because misconceptions are notoriously resilient, Maloney et al. (2001) emphasise the need for continuous formative assessment paired with adaptive teaching moves. Regular diagnostic checks allow instructors to detect lingering misunderstandings about heat and temperature early, adjust explanations, and engineer conceptual-change experiences before misconceptions ossify.

Overall, tackling misconceptions demands a multifaceted approach that combines conceptually driven pedagogy, collaborative learning structures, and sustained formative assessment. When these elements converge, they create the supportive intellectual environment necessary for students to replace naive ideas with scientifically accurate models—ultimately fostering deeper, more durable mastery of fundamental physics concepts.

CONCLUSION

The Four-Tier Multiple-Choice Diagnostic Test successfully profiled Grade-11 students' understanding of temperature and heat. Psychometric checks confirmed good reliability ($\alpha = 0.88$) and item validity (4 of 5 items acceptable). Quantitatively, only 27.3 % of responses indicated accurate, confident understanding, while 45.3 % revealed high-confidence misconceptions, 19.8 % showed partial or uncertain knowledge, and 8.0 % were outright errors. Average test achievement was 30 %, with individual scores ranging from 0 % to 80 %.

Across the five diagnostic items, misconceptions were most acute in analysing the effect of temperature on objects (73.3 % misconceived, 0 % errors), moderate in calorimetry, data correction, and heat-transfer contexts (misconceptions ≥ 46.7 %), and least problematic in phase-change reasoning, where 46.7 % of students demonstrated sound understanding and only 20 % misconceived the concept. These distributions meet the study's objectives by (1) quantifying how many students understand, misconceive, or lack knowledge of each sub-concept; (2) characterising the confidence attached to each epistemic state; and (3) identifying temperature-on-object reasoning as the most persistent conceptual obstacle within the cohort.

RECOMMENDATION

Building on the insights generated by this study, several forward-looking actions are advised. First, the development and deployment of diagnostic tools—particularly the Four-Tier Multiple-Choice Diagnostic Test—should be extended to additional physics domains such as electricity, mechanics, and waves. A broader instrument portfolio will enable educators to construct a comprehensive map of student understanding across the curriculum and to detect topic-specific misconceptions before they harden into persistent barriers. Second, teachers are encouraged to integrate diagnostic findings directly into their instructional design. This entails not only revisiting content where misconceptions predominate but also tailoring pedagogical strategies to students' confidence profiles. High-confidence errors demand conceptual-conflict approaches, whereas low-confidence correct responses call for reinforcement. By systematically addressing both knowledge accuracy and the certainty with which students hold their ideas, educators can foster deeper, more resilient mastery of physics concepts.

ACKNOWLEDGEMENT

The authors gratefully acknowledge SMAN 3 Medan for granting permission and logistical support during data collection, as well as the supervising lecturers and all colleagues whose guidance and constructive feedback greatly assisted the preparation of this article.

REFERENCES

Anggrayni, S., & Ermawati, F. (2019). The validity of four-tier's misconception diagnostic test for work and energy concepts. *Journal of Physics: Conference Series.* https://doi.org/10.1088/1742-6596

Blegur, T. S. (2021). *Identifikasi miskonsepsi tentang suhu dan kalor pada siswa SMA di Kota Kupang menggunakan four-tier diagnostic test* [Undergraduate thesis, Universitas Nusa Cendana].

Dykstra, D., Boyle, C., & Monarch, I. (1992). Studying conceptual change in learning physics. *Science Education, 76*(6), 615–652. https://doi.org/10.1002/sce.3730760605

Fakhruddin, F., Hauwali, N. U. J., Lantik, V., & Gelole, M. G. (2024). Analisis miskonsepsi siswa menggunakan metode four-tier diagnostic test dengan certainty of response index (CRI) pada materi suhu dan kalor. *Schrodinger Jurnal Ilmiah Mahasiswa Pendidikan Fisika, 5*(1), 10–15.

Fariyani, Q., Rusilowati, A., & Sugianto. (2015). Pengembangan four-tier diagnostic multiple choice diagnostic test untuk mengungkap miskonsepsi fisika siswa SMA kelas X. *Journal of Innovative Science Education, 4*(2), 41–49.

Febrianti, J., Akhsan, H., & Muslim, M. (2019). Analisis miskonsepsi suhu dan kalor pada siswa SMA Negeri 3 Tanjung Raja. *Jurnal Inovasi dan Pembelajaran Fisika, 6*(1), 90–102.

Hardy, I., Jonen, A., Möller, K., & Stern, E. (2006). Effects of instructional support within constructivist learning environments for elementary school students' understanding of "floating and sinking." *Journal of Educational Psychology, 98*(2), 307–326. https://doi.org/10.1037/0022-0663.98.2.307

Hatika, R. G., Daruwati, I., & Sohibun, S. (2022). Identifikasi miskonsepsi mahasiswa Prodi Pendidikan Fisika Universitas Pasir Pengaraian pada materi listrik statis. *Jurnal Ilmiah Wahana Pendidikan, 8*(23), 393–399.

Kade, A., Degeng, I., & Ali, M. (2019). Effect of jigsaw strategy and learning style to conceptual understanding on senior high school students. *International*

Journal of Emerging Technologies in Learning, 14(19), 4–11. https://doi.org/10.3991/ijet.v14i19.11592

Kim, H., & Im, S. (2021). Pre-service physics teachers' beliefs about learning physics and their learning achievement in physics. *Asia-Pacific Science Education, 7*(2), 500–521. https://doi.org/10.1163/23641177-bja10038

Lestari, A., & Susantini, E. (2020). Pengembangan instrumen tes miskonsepsi menggunakan four-tier test pada materi transpor membran. *Berkala Ilmiah Pendidikan Biologi (BioEdu), 9*(3), 371–377.

Maloney, D. P., O'Kuma, T., Hieggelke, C. J., & Van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *American Journal of Physics, 69*(S1), S12–S23. https://doi.org/10.1119/1.1371296

Maulida, A. F., Zulkarnain, I., & Hidayanto, T. (2023). Analisis miskonsepsi peserta didik menggunakan tes diagnostik four-tier pada mata pelajaran matematika materi aljabar kelas VII. *Mandalika Mathematics and Education Journal, 5*(1), 152–163.

Putri, R. E., & Subekti, H. (2021). Analisis miskonsepsi menggunakan metode four-tier certainty of response index: Studi eksplorasi di SMP Negeri 60 Surabaya. *Pensa E-Jurnal: Pendidikan Sains, 9*, 220–226.

Qurrota, A., & Nuswowati, M. (2018). Analisis miskonsepsi siswa menggunakan test diagnostic multiple choice berbantuan CRI (certainty of response index). *Jurnal Inovasi Pendidikan Kimia, 12*(1), 2108–2117.

Risky, K. T., Djudin, T., & Hamdani, H. (2022). Analisis miskonsepsi siswa menggunakan four-tier diagnostic test ditinjau dari kemampuan berbahasa pada materi suhu dan kalor di kelas VII SMPN 7 Sungai Raya. *Jurnal Ilmiah Profesi Pendidikan, 7*(3b), 1396–1403.

Salamah, U., Khasanah, N., & Hayati, N. (2020). Pengembangan four-tier multiple choice diagnostic test untuk mendeteksi pemahaman konsep kognitif materi katabolisme pada peserta didik XII SMA/MA. *Bioeduca: Journal of Biology Education, 2*(1), 28–39.

Saputri, E. N., Hartatiana, & Mabruroh, F. (2022). Identifikasi miskonsepsi siswa menggunakan tes diagnostik 4 tahap pada materi gerak. *Berkala Fisika Indonesia: Journal Ilmiah Fisika, Pembelajaran dan Aplikasinya, 13*(1), 8–13.

Suparno, P. (2013). *Miskonsepsi dan perubahan konsep dalam pendidikan fisika*. Gramedia Widiasarana Indonesia.

Syah, M. (2014). *Telaah singkat perkembangan peserta didik.* Rajawali Pers.

Tiandho, Y. (2018). Miskonsepsi gaya gesek pada mahasiswa. *Jurnal Pendidikan Fisika dan Keilmuan (JPFK), 4*(1), 1–9.

Winarni, S. (2015). Membedakan salah konsep dan tidak paham konsep. In *Prosiding Seminar Nasional Kimia dan Pembelajarannya" Riset Kimia dan Pembelajarannya Bersinergi Membangun Negeri* (pp. 394-401).