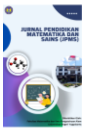

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Comparative Study of Students' Conceptual Understanding in Two Different Curricula on the Light and Electromagnetic Waves Materials

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Abstract

Conceptual understanding involves a deep comprehension of a concept, including the ability to explain, illustrate, and apply it in various contexts. This study aims to compare students' levels of conceptual understanding under the Kurikulum Merdeka and the Cambridge Curriculum. A comparative descriptive method with a mixed-methods approach was used, employing a six-tier diagnostic test, interviews, and classroom observations. The sample consisted of 60 students selected through purposive sampling. The results showed that students following the Kurikulum Merdeka had a higher percentage of scientific understanding (43.4%) compared to those in the Cambridge Curriculum (20.3%). These findings indicate that the effectiveness of instruction is influenced not only by the curriculum strategy but also by factors such as the timing between instruction and assessment, students' confidence in their responses, and language barriers. Therefore, instructional approaches should be aligned with students' cognitive readiness and contextual conditions to optimize conceptual understanding.

Keywords: *Cambridge Curriculum, Conceptual Understanding, Kurikulum Merdeka, Light and Electromagnetic Waves*

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INTRODUCTION

Conceptual understanding involves a student's capacity to internalize and comprehend a concept thoroughly, extending beyond rote memorization to include the ability to explain the idea, illustrate it with examples, connect it to other concepts, and apply it across different situations. It is a fundamental skill that students are expected to possess, as it contributes to the attainment of optimal learning outcomes (Azzahrah Putri et al., 2021; Radiusman, 2020; Safitri et al., 2020). However, various studies have shown that students' understanding of physics concepts remains low, particularly regarding abstract and complex topics such as light and electromagnetic waves (Festiana Purwanti et al., 2023; Nurmawati, 2022).

Students have been found to struggle with understanding concepts related to light, geometric optics, the electromagnetic spectrum, and other properties of light (Festiana Purwanti et al., 2023; Nurmawati, 2022; Triwibowo & Sucahyo, 2017) . Research by Permana Suwarna (2013) also indicates that, while the overall level of misconceptions among high school students is relatively low, misconceptions in optics are considered moderate, with 46.7% of students misunderstanding abstract concepts when connected to concrete examples.

Several factors contribute to this limited conceptual understanding, including unvaried teaching methods, non-contextual learning materials, students' preconceptions, and the influence of culture and learning environments (Febriyana et al., 2020; Hidayat, 2011; Merlina, 2021; Rahmawati, 2024; Rokhim et al., 2023; Sari, 2018) . For example, a less competent teacher might explain only theoretical concepts without conducting practical experiments (Widiarini, 2020), and students with poor scientific communication skills often struggle to engage in discussions and express their ideas clearly (Hakim & Alatas, 2021).

Based on interviews with several physics' teachers in the South Tangerang area, it was found that some teachers simply provided PowerPoint slides and asked students to study them independently. This learning pattern aligns with previous research findings showing that students tend to only recognize surface-level content without developing deeper analytical skills (Entino et al., 2021; Isra & Mufit, 2023). The lack of varied instructional strategies and the absence of comprehensive teaching approaches also contribute to students' weak conceptual understanding (Nurulwati et al., 2014).

These instructional limitations, however, cannot be viewed in isolation from the broader curricular context. Many of the challenges encountered in the learning process are closely linked to how the curriculum is designed and implemented. The curriculum plays a central role in determining how instruction is planned, delivered, and evaluated (Nainggolan et al., 2023). According to Rahayu et al. (2022), the main components of a curriculum include its objectives, instructional strategies or processes, media of delivery, and evaluations used to assess outcomes.

Currently, Indonesia implements the Kurikulum Merdeka as its primary educational framework (Kamiliyah & Faruk, 2023). Interestingly, this curriculum shares several similarities with the international Cambridge Curriculum (Dinurrohmah & Pratomo, 2023). Both curricula emphasize critical thinking skills in their textbooks and focus on student-centered learning, promoting the development of analytical, evaluative, and problem-solving abilities (Adilah et al., 2023; Cambridge Assesment International Education, 2019; Wahyudin et al., 2024). They also encourage the use of technology to enhance effectiveness and engage students in the learning process.

Despite these similarities, the two curricula also differ. The Cambridge Curriculum emphasizes structured international standards in both instruction and assessment (Cambridge Assesment International Education, 2019), while the Kurikulum Merdeka offers greater flexibility to adapt learning materials to local needs (Wahyudin et al., 2024). A notable difference lies in the placement of material within the curriculum structure: light and electromagnetic waves are fully covered in second grade in the Cambridge Curriculum, whereas in the Kurikulum Merdeka, these topics are completed in final grade.

This difference presents an opportunity to examine how the sequencing of content delivery influences students' conceptual understanding. Therefore, this study aims to compare students' conceptual understanding of light and electromagnetic waves under the two different curricula as a basis for improving the quality of physics instruction. Although both the Merdeka and Cambridge Curricula have been widely adopted, studies directly comparing students' conceptual understanding between the two remain limited.

This study employed a six-tier diagnostic test with open-ended reasoning as the main instrument. Diagnostic tests are suitable tools for revealing levels of conceptual understanding (Mufit & Karzah, 2024; Putri et al., 2021; Setiawan & Faoziyah, 2020). The six-tier format is an advancement of the five-tier diagnostic test widely used in previous studies (Yolviansyah et al., 2022). With six systematically designed levels, the test can more thoroughly uncover the root causes and severity of students' conceptual errors (Kusuma et al., 2024; Utami & Khotimah, 2023). In this test, students first answered a multiple-choice question related to a specific concept. The second tier asked them to rate their confidence in the answer they had selected. In the third tier, students provided an open-ended explanation of their reasoning, while in the fourth tier, they assessed their confidence in the reasoning they had written. The fifth tier required them to evaluate the extent to which their reasoning supported their initial answer. Finally, in the sixth tier, students identified the source of their knowledge.

METHOD

This research employed a comparative descriptive method, which aims to compare two or more groups, phenomena, or variables in order to identify similarities and differences (Sugiyono, 2023). Specifically, this study sought to compare students' conceptual understanding of the topics of light waves and electromagnetic waves based on two different curricula, namely the Kurikulum Merdeka and the Cambridge Curriculum. The study was conducted without any treatment or intervention on the research subjects (non-experimental) and aimed to provide an objective overview of students' conceptual understanding profiles within each curriculum.

The research was carried out from March to May during the 2024/2025 academic year in two senior high schools located in Pamulang District, South Tangerang City, Banten Province. SMAN 6 Tangerang Selatan, which applies the Kurikulum Merdeka, is hereinafter referred to as SMAN 6. SMA Kharisma Bangsa, which implements the Cambridge Curriculum, is hereinafter referred to as SMA KB.

The population in this study included all students in SMAN 6 and SMA KB. The accessible population consisted of final grade students in SMAN 6 and second grade students in SMA KB. The sampling technique used was purposive sampling, with the criterion being students who had completed the material related to light waves and electromagnetic waves. The total sample size in this study was 60 students.

The research implementation procedure consisted of four stages, as presented in Table 1.

Table 1. Research procedures

Stage	Activity
Preparation	1. Conduct a literature review. 2. Review the syllabi of the Independent Curriculum and the Cambridge Curriculum. 3. Formulate learning achievement indicators based on the results of the curriculum review.
Preparation of Instruments	1. Prepare the research instruments. 2. Validate the instruments through expert judgment 3. Revise the instruments based on expert feedback 4. Convert the instruments into digital format (Google Form) 5. Conduct a pilot test of the instruments
Implementation	1. Conduct classroom observations 2. Distribute the test instruments 3. Conduct interviews with teachers and students
Processing and Analysis	1. Score the research data based on students' answer combinations 2. Categorize levels of conceptual understanding

This study utilized two types of data, namely quantitative data obtained from diagnostic test results, and qualitative data collected through interviews and classroom observations. The primary instruments used in this study consisted of test and non-test instruments.

The test instrument employed was a six-tier diagnostic test, systematically designed to assess students' conceptual understanding and identify potential misconceptions. This test comprises six components: (1) multiple-choice answers related to basic concepts, (2) confidence level in the answer, (3) open-ended reasoning, (4) confidence level in the reasoning, (5) confidence level in the relationship between the answer and the reasoning, and (6) sources of information used by participants when responding. The test instrument consisted of 20 items. Most of these items were adapted from the Light Phenomenon Conceptual Assessment (LPCA), which was developed to measure students' conceptual understanding of light phenomena (Ndihokubwayo et al., 2020).

The test was constructed with reference to six core subconcepts within the topics of light waves and electromagnetic waves, namely reflection of light, refraction of light, interference and diffraction of light, optical phenomena in daily life, types of electromagnetic waves based on their characteristics, wavelengths, and frequencies, as well as applications of electromagnetic waves and their impacts on life. All subconcepts were mapped and adjusted to align with the learning objectives and scope of content outlined in both the Cambridge Curriculum and the Kurikulum Merdeka, ensuring a balanced and relevant representation of material for each group of students.

The six-tier diagnostic test underwent validation by six experts, resulting in validity indices of 0.86 for content validity, 0.94 for construct validity, and 0.97 for language validity. The instrument was piloted with 136 respondents, and the results showed that all items had r-count values exceeding the minimum threshold of 0.169, indicating that all items were valid. Furthermore, the instrument demonstrated good internal consistency, with a Cronbach's Alpha coefficient of 0.806.

The non-test instruments in this study consisted of interview guidelines and classroom observation sheets. Interviews were conducted to obtain information related to teaching strategies, learning processes, and the perceptions of both teachers and students regarding light waves and electromagnetic waves. Classroom observations were carried out to record the dynamics of the learning process, including teacher–student interactions, media usage, and levels of student engagement during instruction. Data collection in this study was conducted using three main techniques: (1) administering diagnostic tests to students via the Google Form platform, (2) conducting interviews with teachers and selected students from each school, and (3) directly observing classroom learning activities. All data were collected in real time and thoroughly documented.

The data obtained were analyzed using both quantitative and qualitative approaches, depending on the type of instrument. Diagnostic test data were analyzed quantitatively using descriptive statistics by categorizing students' combined responses into six categories: scientific understanding, lack of knowledge, false positive, false negative, misconception, and error. Subsequently, the percentage of each category was calculated for each student and classified based on the curriculum they followed.

Meanwhile, data from interviews and classroom observations were analyzed qualitatively through the processes of data reduction, data display, and conclusion drawing. This qualitative analysis aimed to identify the underlying causes of students' weak conceptual understanding and to describe the implementation of teaching and learning activities based on the distinctive characteristics of each curriculum. Observation data served as supporting evidence in interpreting the results of the diagnostic test.

RESULTS AND DISCUSSION

The results of the analysis of the combined data from the six-tier test answers indicate variations in the level of conceptual understanding among students from both schools. The percentage results for each category of students' conceptual understanding level are presented in Table 2.

Table 2. Percentage results of student understanding level categories

Code	SMAN 6	SMA KB
Scientific understanding	43.4%	20.3%
Lack of knowledge	25.3%	44.3%
False negative	11.8%	9.3%
False positive	8.1%	3.8%
Misconception	7.1%	6.5%
Error	4.4%	15.5%

The results of the analysis indicate that SMAN 6 students demonstrated the highest level of scientific understanding (43.4%), whereas students from SMA KB were primarily categorized under the lack of knowledge group (44.3%). This suggests that SMAN 6 students tended to grasp scientific concepts, while a majority of SMA KB students had not yet mastered the fundamental concepts assessed. The proportion of students in the error category was lowest at SMAN 6 (4.4%), while at SMA KB, the false positive category accounted for the smallest percentage (3.8%).

Overall, SMAN 6 students displayed a stronger profile of conceptual understanding, whereas SMA KB students encountered greater challenges, as reflected by the higher percentages of both lack of knowledge and error combined (15.5%). Meanwhile, the rate of misconceptions was relatively similar across both schools, indicating that conceptual misunderstandings remain a common issue. This pattern highlights that such misconceptions are not limited to a specific curriculum, but are likely influenced by the nature of instructional practices within the classroom environment. Similar findings were reported by Kaltakci-Gurel et al. (2017), who demonstrated that misconceptions in geometrical optics persisted among pre-service physics teachers despite the implementation of modern curricula, largely due to instructional approaches that failed to directly address these misconceptions. Furthermore, Kurniasari et al. (2024) emphasized that while learning media contribute to enhancing students' understanding, the effectiveness of conceptual learning is also shaped by other factors, including teacher quality, school support systems, and students' individual characteristics.The following figure presents a profile of students' conceptual understanding in terms of cognitive process achievement.

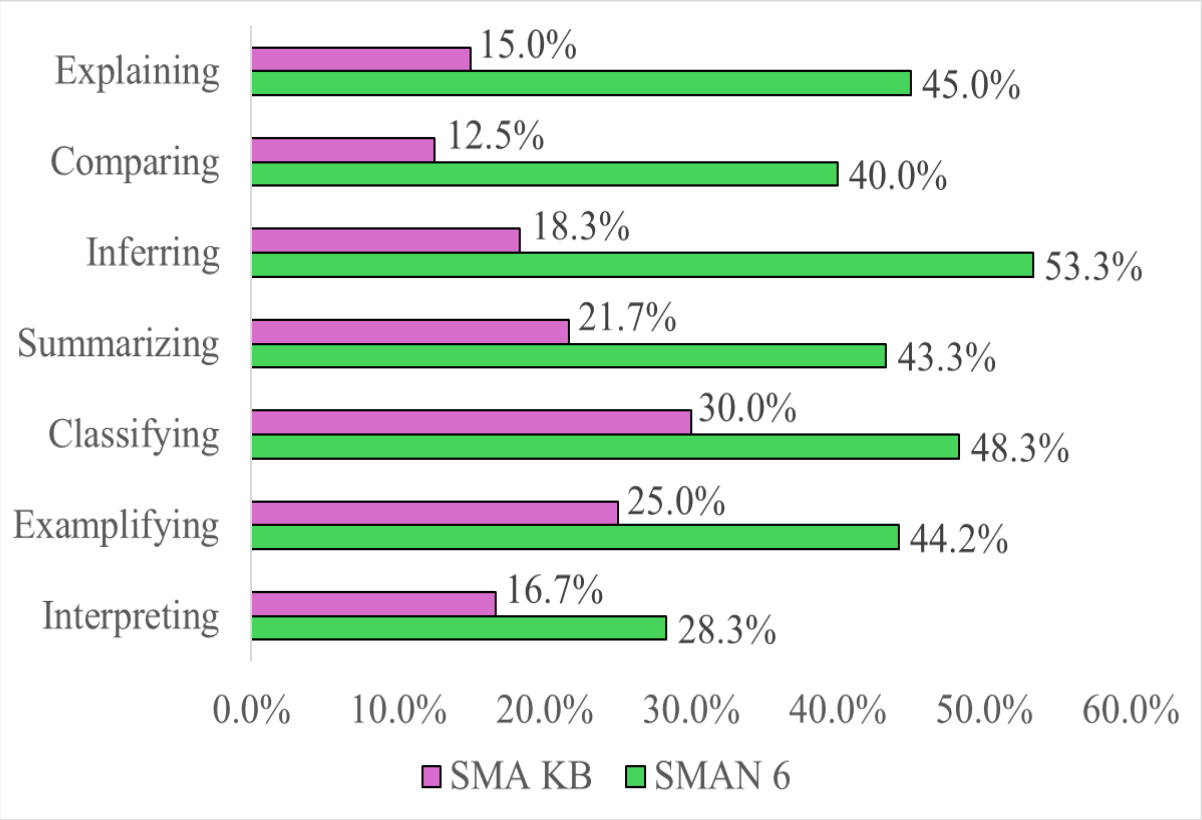

Figure 1. Students' conceptual understanding based on cognitive process achievement

Based on the chart in Figure 1, the highest-achieving indicator at SMAN 6 was *Inferring*, with a score of 53.3%. This suggests that the majority of SMAN 6 students were able to draw logical conclusions from the information provided, reflecting a relatively strong mastery of mid-level thinking skills. In contrast, the highest score at SMA Kharisma Bangsa was on the *Classifying* indicator, with a percentage of 30.0%. This indicates that students found it easier to categorize the concepts they had learned, although this figure remained below SMAN 6's achievement on the same indicator (48.3%).

On the other hand, the lowest-scoring indicator at SMAN 6 was *Interpreting* (28.3%), while at SMA Kharisma Bangsa, the lowest was *Comparing* (12.5%). These low achievements indicate that SMA KB students encountered difficulties in comparing concepts or identifying similarities and differences between ideas, while SMAN 6 students still struggled to interpret information or understand deeper meanings.

This comparison reveals that, in general, SMAN 6 students possess stronger cognitive understanding skills, particularly in the areas of reasoning and concept classification. Conversely, SMA Kharisma Bangsa students continue to face significant challenges, especially in the skills of comparing and drawing scientific inferences related to physics concepts.

Figure 2 presents students' levels of conceptual understanding across each tested sub-concept. Based on the chart, the subconcept with the highest level of understanding among SMAN 6 students was *Applications of Electromagnetic Waves and Their Impact on Daily Life* (Item 6), with a percentage reaching 63.8%. This indicates that SMAN 6 students demonstrated a relatively strong ability to connect physics concepts with real-world phenomena. In contrast, the highest-performing subconcept at SMA KB was *Types of Electromagnetic Waves Based on Characteristics, Wavelength, and Frequency* (Item 5), with an achievement rate of 33.8%. Although it represented the highest score within that school, it remained lower than SMAN 6's performance on the same item (49.4%).

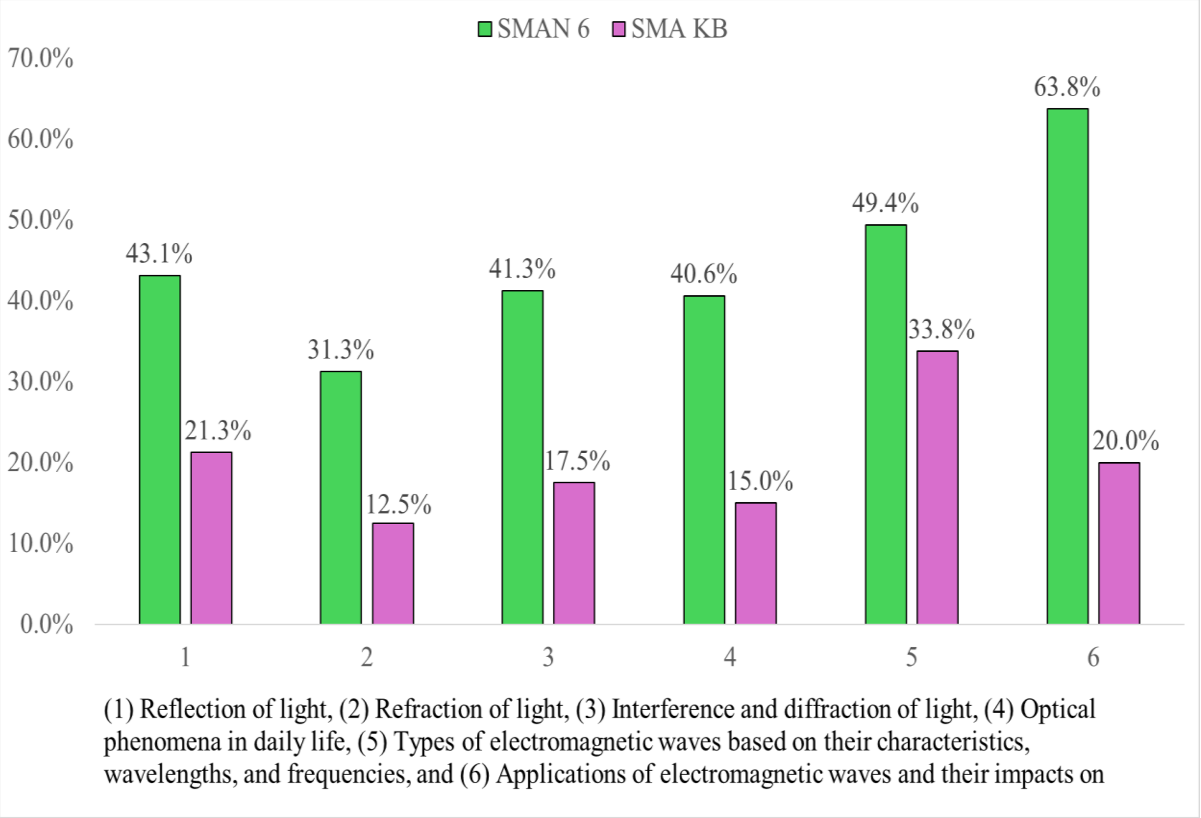

Figure 2. Students' conceptual understanding based on subconcepts

Conversely, the lowest achievement in both schools was recorded on the Refraction of Light subconcept (Item 2). At SMA KB, the percentage reached only 12.5%, indicating considerable difficulty in understanding basic concepts related to changes in the direction of light. Similarly, SMAN 6 students also demonstrated their lowest performance on the same subconcept, although their score was relatively higher at 31.3%.

Comparatively, these findings indicate that although both schools faced similar challenges on this particular subconcept, SMAN 6 students consistently displayed a higher level of understanding across both foundational and application-based physics content. This gap suggests a difference in the effectiveness of instructional approaches implemented at each school.

This finding is consistent with the results of Kaewkhong et al. (2010) and Nasir et al. (2021), who reported that the refraction of light is a subconcept that frequently triggers persistent misconceptions, even after the implementation of interactive learning strategies. In the Indonesian context, Pasaribu et al. (2023) similarly documented misconception rates on the refraction subconcept ranging from 10% to 14%, which align with the low levels of conceptual understanding on this topic observed in SMAN 6 and SMA KB. This consistency highlights that despite efforts to enhance learning through visual media and teaching aids, misconceptions in light refraction remain prevalent across different learning contexts.

Figure 3 below presents the average information sources students used while reasoning through the questions. At SMAN 6, personal thinking emerged as the dominant source of information (50%), followed by the use of the internet (26%). This indicates that half of the students relied on personal reasoning, while a significant portion actively sought additional information from online sources. In contrast, teacher explanations were utilized by only 7% of students, suggesting that the teacher's role had not yet become a primary reference when answering questions. At SMA KB, reliance on personal thinking was even higher, reaching 80%. This suggests that the majority of students responded based on individual logic or assumptions, which may not always be accurate. The least utilized source was books (1%), indicating that engagement with formal instructional materials remained exceptionally low.

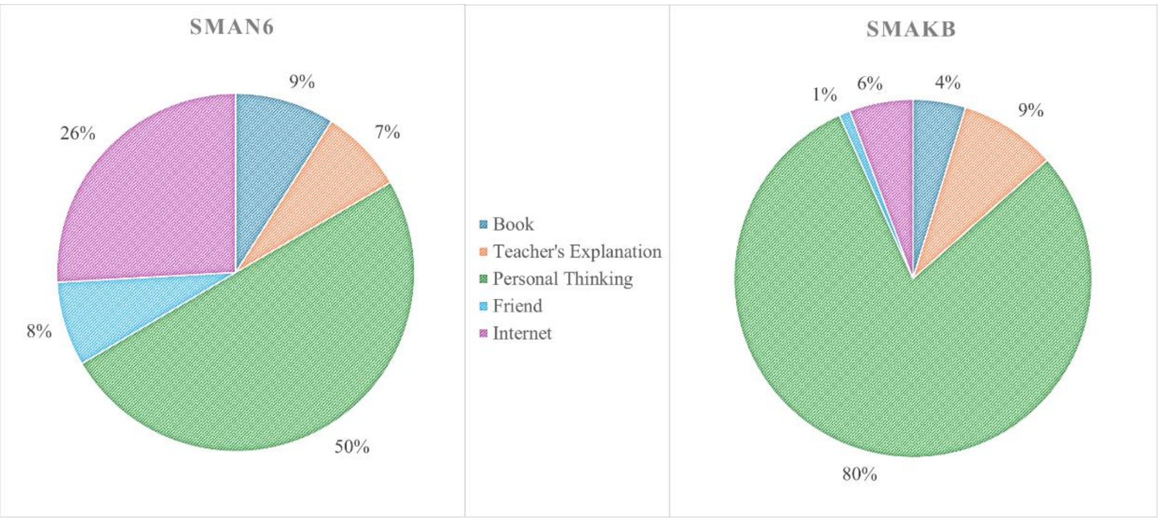

Figure 3. Average use of information sources during student reasoning

These findings are in line with the studies by Ilyas & Saeed (2018) and Jannah et al. (2022), who found that students often construct misconceptions based on personal mental frameworks developed independently, without the support of conceptual clarification strategies provided by teachers. In addition, a literature review conducted by Resbiantoro et al. (2022) concluded that students' misconceptions are often stereotypical in nature, formed through a combination of daily experiences and intuitive understanding, particularly when scientific conceptual frameworks and teacher interventions are not explicitly integrated into the learning process.

Table 3 below presents the results of interview data reduction, summarizing the characteristics of the learning process, challenges encountered, and solutions implemented at SMAN 6 and SMA KB.

Table 3. Summary of interview data reduction

Indicator	SMAN 6	SMA KB
Instructional Media	1. PowerPoint and school textbooks. 2. Frequently use other digital media (YouTube videos).	1. PowerPoint, boardworks and teaching aids (laser pointer, glass block, flat mirror, semicircular acrylic). 2. Frequent use of other digital media (PhET, oPhysics, YouTube videos).
Learning strategies	1. Focus on the delivery of material from the teacher. 2. Students are given space for independent exploration (creating a resume).	1. Guided inquiry, problem solving, and simple experiments. 2. Students are given space for independent exploration (projects and practice).
Learning Evaluation	1. Practice questions and quizzes. 2. Group presentations only occasionally. 3. Assessment tends to focus on the end result (product).	1. Worksheets, digital quizzes (Kahoot, Quizizz), problem sets, lab reports. 2. Each project is presented. 3. Assess the scientific process and understanding of concepts, not just the end product.
Learning Barriers	1. Variation in student abilities. 2. Limited time and many national holidays. 3. Students tend to dislike physics compared to other science subjects,	1. Variation in student abilities. 2. Limited time and many national holidays. 3. Students prefer mathematical calculation type questions, they have

Indicator	SMAN 6	SMA KB
	because they think that physics is difficult.	challenges with theoretical concept questions. 4. English as a medium of instruction is a challenge for students who come from non-bilingual backgrounds.
Solution to the Obstacle	1. Maximize practice questions and discussions. 2. Rely on student activity and involvement in formative tasks to support the achievement of KKM. 3. Provide remedial work for students who have not completed their studies.	1. Provide additional classes after school voluntarily. 2. Increase direct experiments (e.g. observing solar panels). 3. Using more contextual and interactive media. 4. Provide an opportunity to collect assignments after school, for those who are slow learners in completing worksheets. 5. Provide remedial work for students who have not completed their studies.

Based on Table 4, instruction at SMA KB was generally more varied and student-centered, supported by interactive media and inquiry-based strategies. However, students at this school continued to face conceptual challenges and language-related barriers. In contrast, SMAN 6 tended to implement a more structured approach, emphasizing the reinforcement of fundamental concepts, as reflected in students' higher levels of conceptual understanding in test results.

Table 4 presents the results of classroom observations, illustrating the implementation of instructional strategies, lesson structure, and the role of teachers in guiding students throughout the learning process.

Table 4. Observation results

Stage	SMAN 6	SMA KB
Instructional Communication		
Explaining learning objectives, learning ideas, learning tasks, and assessment activities	✓	✓
Planning learning that can encourage children to think	✓	✓
Provide clear assignments/instructions	✓	✓
Provides transition signals in explaining one idea with another idea.	✓	✓
Always provide feedback to clarify students' incorrect statements.	✓	✓
Structured Learning		
Conducting assessments of each student's initial abilities and development level	x	x
Delivering presentations or discussions according to the students' development level.	✓	✓
Encourage students to solve problems	✓	✓
Self Evaluation Grant		
Providing different statements or creating dilemmas/paradoxes to test initial conceptions	✓	✓
Guiding students to think independently	✓	✓
Allow students to assess or provide opinions/hypotheses regarding new information accompanied by relevant reasons.	✓	✓
Guiding students to conduct self-assessment to develop their abilities	x	✓

Stage	SMAN 6	SMA KB
Assignment Assignment		
Giving assignments to analyze, underline, summarize and provide conclusions	✓	✓
Provides instructions for performing procedural tasks	✓	✓
Provide information about the benefits of completing the assigned task	x	x
Exemplifying activity steps	✓	✓
Providing feedback to train students' critical thinking skills	✓	✓
Memberikan pertanyaan terbuka agar siswa dapat menejelaskan dengan gagasan sendiri	✓	✓

Based on Table 4, both schools demonstrated similar practices in instructional communication and task assignment. However, SMA KB stood out by providing more opportunities for reflection through self-assessment, which was not yet observed at SMAN 6. Furthermore, neither school had implemented initial ability assessments nor clearly explained the intended benefits of assignments to students.

The results of the six-tier diagnostic test revealed that students at SMAN 6 exhibited a higher level of conceptual understanding compared to those at SMA KB. Specifically, 43.4% of SMAN 6 students were categorized under scientific understanding, while only 20.3% of SMA KB students achieved this category. In contrast, 44.3% of SMA KB students were identified as lacking knowledge, indicating difficulty in connecting the learned concepts with the correct answers.

These findings indicate a discrepancy between the instructional approaches used and the conceptual outcomes achieved. Although SMA KB implemented a more varied and student-centered approach supported by interactive media such as PhET simulations, experiments, and project-based learning, their students showed lower conceptual gains than those at SMAN 6, which adopted a more conventional and structured teaching strategy. This gap suggests that instructional design alone may not determine learning effectiveness and that cognitive and contextual factors play a significant role.

One such factor is metacognitive confidence. Many SMA KB students provided scientifically correct reasoning but selected answers with low confidence, resulting in their classification under lack of knowledge. This supports the findings of Stankov et al. (2012), who argued that students with low metacognitive confidence tend to struggle in forming stable conceptual representations, even when they possess foundational understanding.

Further evidence from teacher interviews at SMA KB revealed that students preferred numerical problem-solving over conceptual questions. Even with the use of interactive media, they experienced difficulty in interpreting theoretical problems. This reflects a pattern of shallow processing, where students only grasp surface-level understanding without deeper internalization, which explains the persistently low levels of scientific understanding despite engaging teaching methods.

Timing of instruction also contributed to the observed outcomes. SMA KB students studied the topics of light and electromagnetic waves incrementally from Grade 9 through the beginning of Grade 11, resulting in a significant delay between instruction and assessment. This aligns with Forgetting Curve (Murre & Dros, 2015), which demonstrates that unrehearsed information fades over time. Conversely, SMAN 6 students completed the topic closer to the assessment date, benefiting from the recency effect that facilitates better recall of recently learned material.

Language barriers also emerged as a significant factor. SMA KB uses English as the language of instruction, which can pose challenges for non-bilingual students. According to Cummins (2008), theory of Cognitive Academic Language Proficiency (CALP), academic language takes longer to develop than everyday conversational language, potentially limiting students' ability to comprehend complex scientific content.

Taken together, these findings underscore that conceptual understanding is not solely determined by teaching strategies but also by students' cognitive readiness, confidence, timing of instruction, and language proficiency. SMAN

6's stronger performance may be attributed to its structured instructional approach and the closer alignment between learning and assessment, while SMA KB's innovative methods may have been hindered by conceptual consolidation difficulties and linguistic challenges.

To address these challenges, instructional strategies should be not only methodologically diverse, but also contextually relevant and grounded in student experience. For example, STEM-based phenomenon learning has been shown to effectively engage students cognitively by linking scientific concepts with real-world contexts (Suryadi et al., 2021). The POE2WE model also appears promising for fostering scientific communication skills, such as logical argumentation and explanation (Alatas, Setiawan, & Suryadi, 2024). Finally, incorporating elements of cognitive apprenticeship, which has been proven to enhance student motivation by up to 85% (Isma & Nurlaela, 2024), offers long-term potential to reinforce students' conceptual understanding through increased engagement and sustained learning habits.

CONCLUSION

This study concludes that although SMA KB implemented more innovative and student-centered learning strategies, students from SMAN 6 demonstrated a higher level of conceptual understanding. This difference suggests that the success of instructional approaches is not solely determined by the strategies used, but also by other factors such as the structure of material delivery, the timing of instruction relative to assessment, students' confidence in their knowledge, and language-related barriers. These findings imply that effective learning outcomes depend significantly on how students process, internalize, and believe in the knowledge they acquire. Therefore, it is important for schools to integrate instructional strategies with students' cognitive readiness and contextual conditions to optimize their conceptual understanding.

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