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Effectiveness of Augmented Reality-Integrated Cognitive Conflict-Based Teaching Material in Enhancing Students' Conceptual Understanding and Attitudes Toward Physics on Light Waves Topic

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ABSTRACT

Physics learning is expected not only to improve students' conceptual understanding but also to foster positive attitudes toward physics as an essential component of 21st-century skills. However, the abstract nature of light-wave concepts often leads to misconceptions, low conceptual understanding, and unfavorable attitudes toward physics. To address these issues, cognitive conflict-based teaching materials integrated with Augmented Reality (AR) were developed to facilitate conceptual change and provide more concrete visualizations of abstract phenomena. This study investigated the effectiveness of these teaching materials in improving students' conceptual understanding and attitudes toward physics on the topic of light waves. A quantitative approach with a quasi-experimental nonequivalent pretest–posttest control group design was employed. The participants were two eleventh-grade classes at SMAN 3 Padang selected through purposive sampling. Data were collected using a four-tier multiple-choice diagnostic test and an attitude questionnaire. The results showed that the percentage of students categorized as understanding concepts increased to 96.00% in the experimental class, while misconceptions decreased to 0.29%. The Mann–Whitney test revealed a significant difference in conceptual understanding, and the Independent Samples t-test indicated a significant difference in students' attitudes toward physics between the experimental and control groups ($p < 0.05$). These findings demonstrate that AR-integrated cognitive conflict-based teaching materials effectively enhance both conceptual understanding and attitudes toward physics.

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INTRODUCTION

Physics learning in the 21st century is expected to focus not only on conceptual mastery but also on fostering students' positive attitudes toward physics. This expectation aligns with the demands of 21st-century skills, which emphasize a balance between cognitive and affective aspects, alongside the development of critical thinking, creativity, collaboration, and communication skills (Kurniawan & Kuswanto, 2025; Lestari, 2021). These competencies highlight the importance of learning processes that actively engage students in constructing knowledge through meaningful learning experiences. Physics learning is not merely focused on the transmission of information, but also on developing students' ability to understand concepts in depth.

Conceptual understanding is a fundamental aspect of physics learning because it serves as the basis for students to comprehend physical principles, explain relationships among concepts, and apply these concepts to solve various scientific problems. Strong conceptual mastery enables students not only to memorize facts or formulas but also to explain physical phenomena conceptually and use them in different contexts. In addition, conceptual understanding is closely related to critical thinking skills, as a deeper understanding of concepts enhances students' ability to analyze, evaluate, and draw conclusions about a problem (Mindia et al., 2024). This indicates that conceptual understanding not only contributes to improved learning outcomes but also serves as a foundation for the development of higher-order thinking skills required in the 21st century.

In addition to conceptual mastery, physics learning in the 21st century is also expected to develop students' positive attitudes toward physics as part of the achievement of holistic competencies. In the context of physics learning, attitude is the result of the learning process that influences how students perceive, respond to, and participate in learning activities (Rama Dini, 2021). Students who have positive attitudes tend to be more enthusiastic, more persistent when facing difficulties, and more motivated to understand physics concepts, thereby supporting better learning processes and outcomes (Rizkita & Mufit, 2022). Recent studies show that students' attitudes toward physics are positively related to learning engagement and academic achievement, where more positive attitudes toward physics are associated with higher learning performance (Azizah & Yogihati, 2024).

However, many research findings indicate that students' grasp of physics concepts is often insufficient, and misunderstandings continue to exist in different areas of physics (Pratiwi et al., 2025). This low level of conceptual understanding is often attributed to learning processes that have not fully facilitated students' active construction of knowledge and the revision of their initial incorrect conceptions. According to constructivist theory, students construct their knowledge based on prior experiences and pre-existing conceptions. Learning is not merely intended to provide new information but also to help students reorganize their existing knowledge structures so that they align with scientific concepts. When students' initial conceptions are inconsistent with scientific concepts, a learning process that encourages students to evaluate and revise their understanding is required to promote meaningful conceptual change (Akmam et al., 2025; Partono et al., 2024).

These challenges are particularly evident in the learning of light waves, as this topic is highly abstract and difficult to observe directly. The topic encompasses various concepts, such as interference, diffraction, polarization, and dispersion, all of which require strong visualization skills to be fully understood. Limited visualization in conventional learning environments may hinder students from developing accurate mental representations, resulting in persistent misconceptions related to these concepts (Atiqah & Mufit, 2024; Guntara et al., 2023). To address this issue, technological support that can provide more concrete and interactive visualizations of physical phenomena is needed to facilitate students' knowledge construction processes (Mufit & Dhanil, 2024).

Alongside cognitive factors, physics education must also consider affective elements, especially students' feelings about physics. Attitudes toward physics involve students' inclinations to react either positively or negatively to physics and the learning experience, evident through their interest, curiosity, and embrace of scientific attitudes during educational activities. These mindsets affect how students view, emotionally respond to, and act during their physics education. Students who possess positive attitudes generally participate more actively in learning activities, show increased motivation to learn, and exert more effort to achieve a deeper comprehension of physics concepts. In physics education, students' attitudes may manifest in various aspects, such as the societal relevance of physics, eagerness to dedicate additional time to physics study, embracing scientific mindsets, and the pleasure derived from learning physics (Zulrahayu & Mufit, 2024). On the other hand, negative feelings can diminish students' engagement in learning activities and lead to diminished levels of conceptual comprehension.

A preliminary investigation carried out at SMAN 3 Padang indicated that students' comprehension of the topic of light waves remained quite limited. The findings from the initial study regarding students' conceptual understanding are shown in Table 1.

Table 1. Results of Conceptual Understanding Test

Category	Percentage (%)
Conceptual Understanding (CU)	44.06
Not Understanding (NU)	24.06
Misconception (MC)	31.88

The data presented in Table 1 indicate that more than half of the students still experience conceptual difficulties in the topic of light waves, this finding suggests that the current learning process has not been fully effective in developing accurate conceptual understanding and overcoming misconceptions. According to constructivist theory, students construct knowledge based on their prior experiences and existing conceptions. Learning should not only provide new information but also facilitate the reorganization of students' existing knowledge structures to align with scientific concepts. When students' initial conceptions differ from scientific explanations, learning experiences should encourage them to evaluate and revise their understanding, thereby promoting meaningful conceptual (Akmam et al., 2025; Partono et al., 2024)

In addition to examining the cognitive aspect, the preliminary study also explored students' attitudes toward physics to provide a broader description of the existing learning conditions. Identifying students' attitudes offers complementary information regarding their perceptions and responses to physics learning. These findings serve as supporting evidence for describing the context of the study. A summary of the preliminary study findings regarding students' attitudes toward physics is presented in Table 2.

Table 2. Attitudes Toward Test Results

Indicator	Bad (%)	Poor (%)	Good (%)
Social Implications of Physics	0	43.75	56.25
Interest in Spending More Time in Physics Lessons	15.63	84.37	0
Adoption of Scientific Attitudes	15.62	81.26	3.12
Enjoyment in Learning Physics	9.38	68.75	21.87

The information shown in Table 2 suggests that the majority of students have not yet exhibited favorable attitudes toward learning physics. Their limited interest in further exploring physics topics and the insufficient adoption of scientific attitudes may hinder their engagement in the learning process. In contrast, students with positive attitudes toward physics tend to participate more actively in learning activities, exhibit higher motivation to understand concepts, and achieve better learning outcomes than those with negative attitudes toward physics (Fauziah et al., 2021).

To identify the factors contributing to this condition, the researcher conducted an interview with a physics teacher at SMAN 3 Padang. The results indicated that learning activities were still dominated by printed textbooks, which limited students' opportunities to recognize misconceptions, develop conceptual understanding, and engage actively in learning. Furthermore, the teaching materials provided insufficient visual representations for abstract physics concepts, causing learning to become more teacher-centered and less meaningful. The use of informative and less contextual teaching materials encourages students to memorize concepts rather than develop deeper understanding and connect physics concepts with real-life phenomena (Siregar et al., 2024). Therefore, innovative instructional approaches are needed to improve students' conceptual understanding and develop positive attitudes toward physics.

A method that could potentially tackle these challenges is learning based on cognitive conflict. This method highlights the display of phenomena that challenge students' original beliefs, thus fostering a shift in understanding toward more scientifically accurate ideas. Cognitive conflict-oriented learning includes four key phases activating existing beliefs and misunderstandings, introducing cognitive dissonance, discovering and reconciling concepts, and engaging in reflection (Mufit & Dhanil, 2024). Throughout these phases, learners are prompted to assess their original ideas and reshape their comprehension to align with scientific principles. Various research has demonstrated that cognitive conflict is successful in addressing misconceptions and enhancing students' conceptual comprehension (Hasanah et al., 2020; Makhrus & Busyairi, 2022). Furthermore, the use of cognitive conflict can beneficially affect students' perceptions of learning physics (Agusto et al., 2025).

However, the efficacy of cognitive conflict primarily relies on the caliber of the phenomena shown to students. In the field of light waves, which is fundamentally abstract, cognitive conflict necessitates teaching assistance that can illustrate phenomena in a more tangible way. A technology that could address this requirement is Augmented Reality (AR), which interacts with real-world settings by incorporating virtual objects. In physics education, AR can make visible phenomena that are hard to observe directly, thus aiding students in grasping abstract concepts more tangibly (Mufit et al., 2025).

Many research studies have shown the efficacy of AR in learning physics. AR-based educational tools have proven to significantly enhance students' grasp of concepts by offering visual representations of abstract ideas (Khoiriyah et al., 2025). The application of AR has been shown to positively impact students' conceptual comprehension when compared to traditional learning methods (Hidayah et al., 2025). Besides boosting cognitive results, AR can increase students' involvement, learning curiosity, and favorable attitudes toward education by offering a more captivating and interactive educational experience (Basir & Uding, 2025). These results indicate that combining cognitive conflict with AR can lead to a learning experience that aids students in reconstructing erroneous concepts through conceptual conflict while also promoting positive attitudes toward physics by offering more tangible and engaging visual representations of physical phenomena.

Teaching materials that integrate AR and focus on cognitive conflict related to light waves have been created and proven to be both valid and effective for use in physics education (Atiqah & Mufit, 2024). These instructional resources were created to enhance the process of conceptual transformation via cognitive conflict phases aided by AR-supported interactive visualizations. Nonetheless, earlier research has mainly concentrated on the product development phase; thus, the impact of these educational resources on enhancing students' conceptual comprehension and perspectives has not been empirically assessed. As a result, a research gap persists concerning empirical evidence on the impact of AR-integrated cognitive conflict teaching materials on students' cognitive and emotional outcomes.

This study seeks to investigate the impact of Augmented Reality (AR)-enhanced cognitive conflict-based teaching resources related to light waves on enhancing students' conceptual comprehension and attitudes towards physics. This research aims to aid in the creation of educational resources that foster deeper understanding in physics. Along with reducing misunderstandings, the created teaching resources aim to improve students' conceptual comprehension. Additionally, utilizing these educational resources is anticipated to encourage more favorable attitudes among learners during the educational experience.

METHODS

This research utilized a quantitative method with a quasi-experimental design featuring a nonequivalent pretest–posttest control group structure. The study aimed to investigate the impact of cognitive conflict-based teaching materials integrated with Augmented Reality (AR) on students' comprehension and attitudes regarding physics. The instructional resources utilized in this research were created in a prior study and had been validated for teaching purposes (Atiqah & Mufit, 2024). These materials were crafted following the framework of cognitive conflict-based learning, consisting of four phases: activating existing conceptions and misconceptions, introducing cognitive conflict, discovering concepts and reconciling them, and reflection. During the activation phase, students were led to recognize their existing knowledge regarding the subject of light waves.

Augmented Reality (AR) was primarily integrated into the concept discovery and conceptual reconciliation stage. By scanning markers embedded in the teaching materials using smartphones, students were able to access interactive three-dimensional visualizations of light-wave phenomena. These visualizations enabled students to observe phenomena that are difficult to examine directly, such as interference, diffraction, and light dispersion. The teaching materials, therefore, not only facilitated conceptual change through cognitive conflict but also supported conceptual understanding by providing more concrete visual representations. This study was conducted at SMAN 3 Padang during the second semester of the 2025/2026 academic year.

The study group included all students in the eleventh grade at SMAN 3 Padang. The research sample was chosen through purposive sampling, a method based on particular criteria that correspond with the study's goals (Sugiyono, 2013). Prior to sample selection, tests of normality, homogeneity, and mean equality were conducted on students' initial ability data to ensure the equivalence of prior abilities among classes. The findings indicated that Classes XI F1 and XI F2 had comparable initial abilities. Based on these results, Class XI F1 was assigned as the experimental group and was taught using AR-integrated cognitive conflict-based instructional materials, while Class XI F2 served as the control group and was taught using conventional learning materials. The research framework is presented in Table 3.

Table 3. Research Design

Class	Pretest	Treat	Posttest	Attitude Questionnaire
Experiment	O_1	X	O_2	S_1
Control	O_3	-	O_4	S_2

Table 3 presents the research design employed in this study. The symbols $O_1$and O_2 represent the pretest and posttest administered to the experimental class, whereas O_3 and O_4 represent the corresponding pretest and posttest administered to the control class. The symbol X denotes the implementation of AR-integrated cognitive conflict-based teaching materials. Furthermore, S_1 and S_2 represent the attitude questionnaires administered to the experimental and control classes, respectively.

Based on this research design, data were collected using two research instruments. Students' conceptual understanding was measured using a four-tier multiple-choice instrument designed to identify the depth of students' conceptual understanding more comprehensively. The instrument evaluates students' answer choices, confidence levels, and reasoning, allowing a more accurate diagnosis of conceptual understanding and misconceptions than conventional multiple-choice tests. Students' attitudes toward physics learning were measured using a questionnaire adapted from a previous study by Zulrahayu & Mufit (2024). The conceptual understanding instrument was administered before and after the learning intervention, whereas the attitude questionnaire was administered only after the completion of the learning intervention.

The analysis of data utilized both descriptive and inferential statistics. Descriptive statistics were employed to initially characterize the data using the mean, standard deviation, maximum, and minimum values (Aslam, 2024). Later, inferential statistics were utilized to examine the research hypotheses. Prior to hypothesis testing, prerequisite evaluations were first conducted, such as the Shapiro–Wilk test for normality and the test for homogeneity of variance. A normality test was performed to assess whether the data followed a normal distribution, while a homogeneity of variance test was utilized to confirm that the variances among groups were sufficiently consistent, thus meeting the assumptions necessary for employing parametric statistics (Ahadi & Zain, 2023).

An independent-samples t-test was utilized for hypothesis testing to compare the means of two independent groups when the data met the assumptions required for parametric analysis. This test was applied to determine whether there were statistically significant differences between the two groups under normally distributed data conditions. However, when the assumption of normality was violated, the Mann–Whitney U test was used as a nonparametric substitute to assess differences between the two groups (Emerson, 2023). All statistical analyses were conducted using IBM SPSS Statistics 25 to ensure accurate and systematic data processing.

RESULTS AND DISCUSSION

Results

Analysis Results of Students' Conceptual Understanding

Students' conceptual understanding was analyzed using a diagnostic test that categorized students' responses into three groups conceptual understanding (CU), no understanding (NU), and misconceptions (MC). The analysis aimed to examine students' initial understanding before instruction and the changes in conceptual understanding after the implementation of AR-integrated cognitive conflict-based teaching materials. The pretest and posttest results for the experimental and control classes are presented in Tables 4 and 5.

Table 4. Percentage of Students' Concept Understanding in the Pretest

Category	Experiment (%)	Control (%)
Conceptual Understanding (CU)	35.43	31.71
Not Understanding (NU)	46.29	37.71
Misconception (MC)	18.29	30.57

Based on Table 4, the percentage of students categorized as having conceptual understanding (CU) was relatively low, at 35.43% in the experimental class and 31.71% in the control class. In contrast, the highest percentage in both classes was found in the not understanding (NU) category, accounting for 46.29% in the experimental class and 37.71% in the control class. Furthermore, misconceptions (MC) were still observed among students, with percentages of 18.29% in the experimental class and 30.57% in the control class. These findings indicate that most students had not yet attained an adequate conceptual understanding of light wave concepts prior to instruction. The predominance of students in the not understanding category, together with the presence of misconceptions, suggests that many students either lacked sufficient prior knowledge or held conceptions that were inconsistent with scientifically accepted explanations.

After the instructional process was completed, students' conceptual understanding was reassessed through the posttest to examine changes in their understanding of light wave concepts. The posttest results provide an overview of the distribution of students across the categories of conceptual understanding (CU), not understanding (NU), and misconception (MC) after the learning process. Comparing these results with the pretest findings enables an evaluation of the effectiveness of the instructional treatment in improving students' conceptual understanding and reducing misconceptions. The percentage distribution of students in each category is presented in Table 5.

Table 5. Percentage of Students' Concept Understanding in Posttest

Category	Experiment (%)	Control (%)
Conceptual Understanding (CU)	96.00	77.53
Not Understanding (NU)	3.71	13.48
Misconception (MC)	0.29	8.99

Based on Table 5, the percentage of students with conceptual understanding (CU) increased in both classes, with the experimental class showing a higher achievement (96.00%) than the control class (77.53%). The higher CU percentage in the experimental class indicates that AR-integrated cognitive conflict-based teaching materials effectively assisted students in reconstructing their initial conceptions into scientifically accepted concepts. This finding supports Puspita (2022), who stated that cognitive conflict strategies can reduce misconceptions and improve students' conceptual understanding. Furthermore, AR-based visualizations helped students understand abstract light wave concepts more easily, supporting a more effective process of concept construction and understanding.

Although descriptive analysis indicated differences in conceptual understanding between the experimental and control classes, statistical analysis was required to determine whether these differences were statistically significant. Prior to hypothesis testing, therefore, a normality test was conducted on the posttest data to determine the appropriate statistical test for analysis. The results of the Shapiro–Wilk normality test indicated that the data did not satisfy the assumption of normality. Consequently, hypothesis testing was performed using the nonparametric Mann–Whitney U test. The results of the Mann–Whitney U test are presented in Table 6.

Table 6. Results of Mann–Whitney U Test on Posttest

No	Aspects	Value		
		CU	NU	MC
1	Mann-Whitney U	318.500	401.500	378.000
2	Wilcoxon W	948.500	1031.500	1008.000
3	Z	-3.989	-3.112	-3.853
4	Sig. Asim. (2-tailed)	0.000	0.002	0.000

Based on Table 6, the significance values obtained for the categories of conceptual understanding (CU), not understanding (NU), and misconceptions (MC) were all less than 0.05. These results indicate that there were statistically significant differences between the experimental and control classes after the instructional intervention. The significant differences observed suggest that the use of cognitive conflict-based teaching materials integrated with Augmented Reality (AR) had a positive effect on students' conceptual understanding. Students in the experimental class demonstrated higher levels of conceptual understanding and lower levels of not understanding and misconceptions compared to those in the control class.

Analysis Results of Student's Attitude

Attitudes toward physics in this study were measured using four indicators: the social implications of physics, interest in spending more time learning physics, adoption of scientific attitudes, and enjoyment in learning physics. To provide an overview of the data characteristics, descriptive statistical analysis was first conducted on the students' total attitude scores for both the experimental and control classes. The descriptive statistics include the number of participants, mean, standard deviation, minimum score, and maximum score, providing an initial comparison of students' attitudes between the two groups. The results of the descriptive statistical analysis are presented in Table 7.

Table 7. Descriptive Statistics of Attitudes Toward in Experimental and Control Groups

Class	Mean	N	Std. Deviation	Minimum	Maximum
Experiment	113.46	35	15.657	76	143
Control	100.49	35	13.205	71	130
Score	106.97	70	15.792	71	143

Based on Table 7, the descriptive statistical analysis shows that the experimental group achieved a higher mean score than the control group, indicating that students in the experimental class demonstrated better attitudes toward physics learning. The overall mean score of all participants was 106.97 with a standard deviation of 15.792, indicating variations in students' attitude scores across both groups. Before conducting the inferential statistical analysis, prerequisite tests for normality and homogeneity of variance were performed to determine whether the data met the required statistical assumptions. The results showed that the data from both groups were normally distributed and had homogeneous variances, indicating that the data were suitable for further inferential analysis.

Since the assumptions of normality and homogeneity were satisfied, the hypothesis testing was conducted using the Independent Samples *t*-test to determine whether there was a statistically significant difference in students' attitudes toward physics between the experimental and control groups. This analysis was performed by comparing the posttest attitude scores of both groups after the learning process. The results of the Independent Samples *t*-test, including the test statistics and significance value, are presented in Table 8.

Table 8. Results of the Independent Sample T-Test of Attitudes Toward

No	Parameter	Result
1	F	0.113
2	t	3.747
3	df	68
4	Sig. (2-tailed)	0.000

Based on Table 8, the Sig. (2-tailed) value of 0.000 indicates that there was a statistically significant difference in students' attitudes between the experimental and control classes. This finding suggests that the instructional intervention had a significant effect on students' attitudes toward physics. The results indicate that students in the experimental class achieved more positive attitude scores than those in the control class after the learning intervention. This difference demonstrates that the instructional intervention was associated with more positive attitudes toward physics learning. Overall, the findings provide empirical evidence of differences in students’ attitudes between the two classes following the implementation of the learning intervention.

Discussion

The results revealed significant differences between the experimental and control classes across the categories of conceptual understanding (CU), lack of understanding (NU), and misconceptions (MC). These findings indicate that the use of cognitive conflict-based teaching materials integrated with Augmented Reality (AR) had a more positive effect on students’ conceptual understanding compared to conventional instruction. In particular, students in the experimental group demonstrated higher levels of conceptual understanding and lower levels of misconceptions than those in the control group. Overall, the findings suggest that AR-integrated cognitive conflict-based instruction is more effective in improving students’ conceptual understanding while reducing misconceptions.

The observed conceptual change can be attributed to the design of the cognitive conflict-based teaching materials, which confront students with phenomena that contradict their prior conceptions. This mismatch creates cognitive disequilibrium that triggers the re-evaluation and reconstruction of existing knowledge structures. Through stages of Cognitive Conflict-Based Learning (CCBL) including elicitation of prior conceptions, exposure to cognitive conflict, concept discovery, and reflection students are guided to compare their initial ideas with empirical evidence. This process makes learning more meaningful than instruction that primarily emphasizes information transmission (Akmam et al., 2025; Partono et al., 2024) These findings are consistent with previous studies demonstrating that cognitive conflict-based teaching materials are effective in improving students’ conceptual understanding while simultaneously remediating misconceptions (Zuwita & Mufit, 2023). Furthermore, such teaching materials can help students develop a deeper understanding of physics concepts through a systematic process of conceptual change (Defrianti et al., 2021).

The improvement in conceptual understanding observed in the experimental group was also supported by the integration of Augmented Reality (AR) into the teaching materials. The use of AR in this study aligns with the third phase of Cognitive Conflict-Based Learning (CCBL), namely concept discovery and concept reconciliation (Atiqah & Mufit, 2024). Through three-dimensional visualizations and virtual objects, AR provided students with more concrete representations of light wave concepts, helping them construct scientifically accurate understanding while reducing conceptual misinterpretations that lead to misconceptions. This finding is supported by Devana et al., (2025), who reported that integrating AR into cognitive conflict-based teaching materials facilitates knowledge construction and improves students' understanding of physics concepts. In addition, AR enables the visualization of physical phenomena in three dimensions, supports investigative activities, and helps students explain, interpret, and analyze scientific phenomena more effectively. The visualization and interactivity provided by AR also create more meaningful learning experiences than conventional instruction (Mufit & Dhanil, 2024).

The findings of this study are supported by previous research showing that the cognitive conflict approach positively affects physics learning outcomes, particularly students' conceptual understanding (Mufit & Puspitasari, 2020). In addition, conceptual change-oriented instruction has been shown to effectively improve conceptual understanding while reducing students' misconceptions in science learning (Aryani et al., 2024). Consistent with the present study, Nusli et al. (2026) reported that cognitive conflict-based teaching materials integrated with Augmented Reality (AR) significantly improved students' conceptual understanding of light wave concepts and reduced misconceptions compared with conventional instruction. Their findings indicate that the integration of cognitive conflict and AR helps students reconstruct their understanding through interactive visualizations, enabling them to better understand abstract physics concepts. Therefore, the significant differences between the experimental and control groups in this study suggest that integrating cognitive conflict and AR into teaching materials provides a more effective learning approach for developing students' conceptual understanding than conventional instruction.

In addition to improving conceptual understanding, cognitive conflict-based teaching materials integrated with Augmented Reality (AR) also positively influenced students' attitudes toward physics. Improvements were observed across several indicators, including awareness of the social implications of physics, interest in spending more time learning physics, adoption of scientific attitudes, and enjoyment of physics learning. The use of AR enabled students to visualize light wave phenomena more concretely and relate the concepts to real-life technological applications, thereby increasing their awareness of the role of physics in everyday life (Basir & Uding, 2025). This enhanced understanding of the practical relevance of physics contributes to the development of more positive attitudes toward the subject.

The increase in students' interest in spending more time learning physics indicates that the implemented instructional approach was successful in enhancing students' motivation to learn. The integration of AR into the teaching materials created a more interactive and engaging learning experience, thereby stimulating students' curiosity about the subject matter. Furthermore, the cognitive conflict encountered during the learning process encouraged students to seek scientific explanations for the observed phenomena, which in turn increased their willingness to further explore and learn physics. Engaging and intellectually challenging learning experiences have been shown to enhance students' participation and interest in physics learning (Agusto et al., 2025; Basir & Uding, 2025). The combination of cognitive conflict and AR not only promotes active involvement in the learning process but also fosters students' intrinsic motivation to deepen their understanding of physics concepts.

The improvement in the indicator of scientific attitude adoption suggests that students became increasingly accustomed to applying scientific reasoning when interpreting physical phenomena. Cognitive conflict-based learning requires students to examine their prior conceptions, compare them with empirical evidence, and revise inaccurate understandings. This process trains students to think critically, objectively, and openly toward conceptual change based on scientific evidence. The stages of cognitive conflict-based learning, which include the identification of prior conceptions, presentation of cognitive conflict, concept discovery, and reflection, encourage students to evaluate their own understanding and reasoning processes. As a result, these learning activities support the development of scientific attitudes in physics learning (Mufit & Dhanil, 2024; Okeke et al., 2023). By engaging students in evidence-based inquiry and self-reflection, cognitive conflict-based learning fosters habits of mind that are essential for scientific thinking and understanding.

The improvement in students' enjoyment of learning physics indicates that the use of cognitive conflict-based teaching materials integrated with Augmented Reality (AR) was able to create a more engaging and enjoyable learning environment. AR enables students to interact directly with virtual objects, making the learning process more active and less monotonous. Such engaging learning experiences can enhance students' comfort and satisfaction throughout the learning process. Students who are actively involved in learning activities tend to demonstrate more positive attitudes and derive greater enjoyment from the learning experience. The integration of cognitive conflict and AR encourages students to participate actively in constructing their understanding, thereby fostering a more meaningful and enjoyable learning process. Furthermore, previous studies have shown that the combination of cognitive conflict and AR can enhance student engagement and promote positive responses toward 21st-century learning (Agusto et al., 2025; Basir & Uding, 2025). As a result, students become more enthusiastic, motivated, and positively disposed toward learning physics.

The findings of this study are supported by previous research demonstrating that learning environments which provide students with opportunities to actively construct their own knowledge can enhance students' attitudes toward physics. Through active engagement in exploring ideas, testing prior understanding, and connecting concepts with learning experiences, students tend to develop greater interest in and appreciation for physics. These characteristics are consistent with cognitive conflict-based learning, which places students at the center of the learning process and promotes conceptual change (Okeke et al., 2023). This finding is also aligned with the nature of cognitive conflict-based learning, which encourages students to examine their prior conceptions and develop a more scientific understanding through reflection and discussion. Furthermore, the results of this study are supported by previous research indicating that the implementation of cognitive conflict-based Augmented Reality (AR) has a positive impact on students' attitudes toward 21st-century learning (Agusto et al., 2025). The integration of cognitive conflict and AR enhances students' engagement throughout the learning process, making them more enthusiastic, active, and positive toward learning activities. Consequently, students not only achieve better conceptual understanding but also develop more favorable attitudes toward physics learning.

This study stands out by integrating Augmented Reality (AR) with cognitive conflict-based teaching materials to support students' understanding of light wave concepts. The findings show that combining conceptual understanding and students' attitudes can improve both simultaneously, whereas previous studies have generally examined them separately. Improvements were observed across several attitude dimensions, including awareness of the social implications of physics, interest in learning physics, scientific attitudes, and enjoyment of physics learning. These results indicate that the integration of cognitive conflict and AR effectively enhances students' conceptual understanding while also fostering more positive attitudes toward physics, making it a promising and innovative approach for promoting deep and sustainable learning in physics education.

CONCLUSION

This study demonstrates that cognitive conflict-based teaching materials integrated with Augmented Reality (AR) effectively improve students' conceptual understanding and attitudes toward physics in learning light waves. The integration of cognitive conflict strategies with AR visualization helps students reconstruct their initial conceptions, reduce misconceptions, and develop a more accurate scientific understanding of abstract light-wave concepts. Compared with conventional learning, students who used the developed teaching materials showed higher conceptual understanding and a lower tendency to retain misconceptions. In addition to cognitive improvement, the teaching materials also positively influenced students' attitudes toward physics by increasing interest, strengthening appreciation of physics in everyday life, fostering scientific thinking, and enhancing willingness to engage in learning activities.

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