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Effectiveness of Cognitive Conflict-Based Teaching Material Integrated with Augmented Reality in Improving Students' Conceptual Understanding and Self-Efficacy on Light Waves

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ABSTRACT

Effective physics learning should enable students to develop sound conceptual understanding and strong self-efficacy to solve scientific problems. Physics learning on light waves remains challenging due to students' low conceptual understanding, misconceptions, and low self-efficacy caused by abstract concepts and teacher-centered instruction. These challenges highlight the need for innovative teaching materials. This study aimed to investigate the effectiveness of Augmented Reality (AR)-integrated cognitive conflict-based teaching materials in improving students' conceptual understanding and self-efficacy. A quasi-experimental study employing a nonequivalent pretest–posttest control group design was conducted with 36 experimental and 33 control class students at SMA Negeri 1 Batusangkar. Data from a validated four-tier diagnostic test and self-efficacy questionnaire were analyzed using descriptive statistics, Mann–Whitney U, and Independent Sample t-tests. Results showed the experimental class's correct understanding increased from 26% to 80%, while misconceptions decreased from 40% to 8%. Statistical analysis revealed significant differences in conceptual understanding ($p < .001$) and self-efficacy ($p < .001$) between classes. These findings demonstrate that AR-integrated cognitive conflict-based materials effectively enhance both cognitive and affective outcomes, serving as an impactful instructional alternative to overcome learning difficulties in abstract physics topics.

INTRODUCTION

Physics education continues to face various challenges in fostering students' conceptual understanding and self-efficacy. In learning physics, students are not only required to master formulas but also to understand the underlying physical meanings of scientific concepts. Conceptual understanding is an essential aspect because it enables students to interpret, connect, and apply concepts in various problem-solving situations (Wandi et al., 2023). Learning with understanding tends to produce knowledge that is more meaningful, longlasting, and transferable than learning that focuses solely on memorizing formulas (Maharani et al., 2013). Therefore, the development of conceptual understanding is one of the primary objectives of physics education.

Students’ achievement in physics is shaped not only by cognitive competence but also by affective factors. One important affective construct is self-efficacy, which describes how individuals perceive their capability to successfully accomplish particular tasks and goals (Bandura, 1997). In educational contexts, students with stronger self-efficacy tend to demonstrate greater perseverance, exert more effort, and adopt more productive approaches to learning when confronted with academic challenges (Miao et al., 2025; Nurulwati et al., 2020). Conversely, low self-efficacy may lead to reduced learning engagement, weaker problem-solving abilities, and less optimal knowledge retention, particularly when students encounter abstract physics concepts (Cwik & Singh, 2023; Halimatuzzahra et al., 2025; M & Nissen, 2016; Mufit et al., 2025). Therefore, enhancing both conceptual understanding and self-efficacy should be a major concern in physics education.

Despite their importance, physics learning in schools continues to face several challenges. Instruction that is predominantly based on lectures and problem-solving exercises often encourages students to memorize formulas without developing a deep understanding of the underlying concepts, making them more susceptible to misconceptions (Abadiyah, 2025; Jannah et al., 2016). This issue becomes even more pronounced in the topic of light waves, which is abstract in nature and difficult to observe directly. Limited opportunities for visualization hinder students from developing comprehensive conceptual understanding, resulting in misconceptions that are still frequently found in this topic (Atiqah & Mufit, 2024).

To identify the actual learning conditions, a preliminary study was conducted involving twelfth-grade students at SMA Negeri 1 Batusangkar who had previously studied the topic of light waves. The preliminary findings revealed that students' conceptual understanding remained relatively low. Only 24.4% of students demonstrated correct conceptual understanding, whereas 11.6% lacked conceptual understanding and 64.1% exhibited misconceptions. These findings indicate that misconceptions remain the dominant conceptual condition among students. Several misconceptions identified in the topic of light waves include the belief that brighter light travels faster (Suniati et al., 2013), the assumption that the colors observed in soap bubbles are caused by light polarization (Lutfia & Putra, 2020), and the notion that rainbows are formed solely through the process of light dispersion (Rochim et al., 2019). These findings suggest that students continue to experience substantial conceptual difficulties in learning light-wave concepts, indicating the need for instructional approaches that can effectively facilitate conceptual reconstruction.

The preliminary study also examined students' self-efficacy across three dimensions: confidence in performing learning tasks, confidence in attaining learning objectives, and confidence in dealing with learning challenges. The results showed that students generally exhibited low levels of self-efficacy. Only 25% of students demonstrated high confidence in performing learning tasks, while the percentages decreased to 21.9% for confidence in attaining learning objectives and 15.6% for confidence in dealing with learning challenges. In contrast, the proportions of students categorized as having low self-efficacy reached 34.4%, 46.9%, and 53.1% across the three respective dimensions. These findings suggest that many students still lack confidence in their ability to learn physics successfully, highlighting the need for instructional approaches that can simultaneously strengthen conceptual understanding and self-efficacy.

To address these challenges, cognitive conflict-based learning has been proposed as an effective instructional approach. The model facilitates conceptual reconstruction by guiding students through the stages of preconception and misconception activation, cognitive conflict presentation, concept discovery, and reflection (Mufit, 2018). This model is designed to elicit students' prior knowledge, identify misconceptions, and present phenomena that encourage students to construct new understanding through critical thinking processes (Nahdhah & Mufit, 2025). Previous studies have consistently demonstrated that cognitive conflict-based instruction effectively reduces students' misconceptions. Significant reductions in misconceptions have been reported among senior high school students following the implementation of cognitive conflict strategies, with cognitive conflict-based instruction proving more effective than conventional teaching approaches (Hanafi & Supardi, 2019; Hasanah et al., 2020).

However, the ability of cognitive conflict-based learning to facilitate conceptual change is closely related to the quality of the phenomena presented to learners. In the topic of light waves, which is abstract in nature, cognitive conflict requires instructional media capable of visualizing phenomena in a concrete manner. One technology with the potential to support this need is Augmented Reality (AR), which integrates virtual objects into the real environment in an interactive way. In physics education, AR can visualize phenomena that are difficult to observe directly, thereby helping students understand abstract concepts more concretely (Cai et al., 2021).

Previous research has provided evidence of the positive contribution of AR to physics learning. Cai et al. (2021) reported that AR-supported learning not only enhanced students' self-efficacy compared with conventional instruction but also promoted higher-order learning conceptions, including understanding, applying, and viewing concepts from new perspectives. Similarly, Khoiriyah et al. (2025) found that AR-based physics learning media effectively improved students' conceptual understanding by visualizing abstract concepts. Likewise, Hidayah et al. (2025) reported that the use of AR supported by Assemblr Edu produced better conceptual understanding than conventional learning. Furthermore, Mufit et al. (2025) demonstrated that cognitive conflict-based teaching materials integrated with AR significantly improved students' self-efficacy.

Although numerous studies have shown that cognitive conflict is effective in reducing misconceptions and that AR effectively enhances both students' conceptual understanding and self-efficacy, research integrating these two approaches into teaching materials remains limited. The integration of cognitive conflict and AR has the potential to create a learning experience that not only helps students reconstruct incorrect concepts through conceptual conflict but also visualizes abstract phenomena in a more concrete manner. Therefore, cognitive conflict-based teaching materials integrated with AR represent an instructional innovation with the potential to simultaneously improve students' conceptual understanding and self-efficacy.

Following this instructional approach, AR-integrated cognitive conflict-based teaching materials on the topic of light waves were developed by Atiqah and Mufit (2024) and were found to be valid and practical for classroom use. Although these findings indicate that the teaching materials are feasible for implementation, they do not provide evidence of their effectiveness in improving students' learning outcomes. In educational research, evidence of effectiveness is essential to determine whether a learning product achieves its intended instructional objectives. To date, the effectiveness of these teaching materials in enhancing students' conceptual understanding and self-efficacy has not yet been empirically examined. Therefore, further research is needed to provide empirical evidence regarding the effectiveness of these teaching materials in supporting cognitive and affective learning outcomes in physics.

Based on the foregoing discussion, this study aims to provide empirical evidence regarding the effectiveness of AR-integrated cognitive conflict-based teaching materials on the topic of light waves in improving students' conceptual understanding and self-efficacy. Specifically, the study investigates whether students who learn using these teaching materials demonstrate better conceptual understanding and higher self-efficacy than those who receive conventional instruction supported by printed textbooks. The findings are expected to enrich the growing body of knowledge on the integration of cognitive conflict pedagogy and Augmented Reality (AR) technology in physics education by providing empirical evidence of its impact on both cognitive and affective learning outcomes. Furthermore, this study offers an alternative approach for developing innovative physics teaching materials that facilitate conceptual reconstruction, support the learning of abstract concepts through interactive visualization, and foster students' confidence in learning physics.

METHODS

This study employed a quantitative approach using a quasi-experimental method with a nonequivalent pretest–posttest control group design adapted from Sugiyono (2023). The design was employed to investigate the effectiveness of AR-integrated cognitive conflict-based teaching materials on students' conceptual understanding and self-efficacy. It was considered appropriate because the existing classroom groups could not be randomly assigned while still allowing comparisons between the experimental and control groups. The research design is presented in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Posttest	Self-Efficacy Test
Experimental Group	O_1	X	O_2	SE_1
Control Group	O_3	-	O_4	SE_2

Source: Adapted from Sugiyono (2023).

Description:

O_1 : Pretest of the experimental group
O_2 : Posttest of the experimental group
O_3 : Pretest of the control group
O_4 : Posttest of the control group
X : Implemented AR-integrated cognitive conflict-based teaching materials
SE_1: Self-efficacy test of the experimental group
SE_2: Self-efficacy test of the control group

The population of this study consisted of all students enrolled in Grade XI Physics classes at SMA Negeri 1 Batusangkar, including classes XI F1, XI F2, XI F4, and XI F7. The sample was selected using a purposive sampling technique, which involves selecting samples based on specific considerations aligned with the objectives of the study (Sugiyono, 2023). Three classes were selected as the research sample: XI F1 (36 students), XI F4 (33 students), and XI F7 (31 students). These classes were chosen because they were taught by the same physics teacher.

Before assigning the experimental and control groups, a validated four-tier diagnostic instrument was administered to students in all three classes to evaluate their conceptual understanding. The pretest data were subsequently examined through normality, homogeneity, and mean-equivalence tests to verify that the participating classes had comparable initial abilities. After the three classes were confirmed to have equivalent initial abilities, the experimental and control groups were determined through a random assignment procedure. The random assignment resulted in class XI F1 being designated as the experimental group and class XI F4 as the control group. The experimental group received instruction using AR-integrated cognitive conflict-based teaching materials, whereas the control group received direct instruction supported by the printed textbook commonly used in the school.

Two instruments were employed: a four-tier multiple-choice diagnostic test and a self-efficacy questionnaire. Students' conceptual understanding was assessed before and after the intervention using a four-tier multiple-choice diagnostic test, whereas self-efficacy was measured only after the intervention using a questionnaire. The conceptual understanding instrument initially consisted of 20 items, of which 10 items with acceptable psychometric properties were retained following validity, discrimination, difficulty, and reliability analyses (validity = 0.539–0.878; Cronbach's α = 0.820). Self-efficacy was measured using a validated questionnaire adapted from Putri and Usmeldi (2023), which was constructed based on previously validated self-efficacy instruments. The instrument demonstrated good psychometric properties, with Cronbach's α = 0.83, Composite Reliability = 0.88, Average Variance Extracted (AVE) = 0.55, and outer loading values ranging from 0.71 to 0.81. Self-efficacy was evaluated through three indicators, namely confidence in performing learning tasks, attaining learning objectives, and dealing with learning challenges. The questionnaire consisted of 22 statements rated on a five-point Likert scale.

Both descriptive and inferential statistics were employed to analyze the data. Descriptive statistics were used to summarize the data through the mean, standard deviation, minimum value, and maximum value. Before hypothesis testing, normality and homogeneity were examined using the Shapiro–Wilk and Levene's tests, respectively. The null hypothesis stated that no significant differences existed in students' conceptual understanding and self-efficacy between the experimental and control groups, whereas the alternative hypothesis stated that significant differences existed between the two groups. When the assumptions of normality and homogeneity were satisfied, an Independent Samples *t*-test was used; otherwise, the Mann–Whitney U test was applied. Statistical significance was determined at $p < 0.05$ (Ghozali, 2018). All analyses were performed using IBM SPSS Statistics 25.

RESULTS AND DISCUSSION

Results

Students' conceptual understanding was analyzed using a four-tier diagnostic test that classified students' responses into three categories: correct conceptual understanding (CCU), lack of conceptual understanding (LCU), and misconception (M). The analysis aimed to examine students' conceptual understanding before and after the implementation of AR-integrated cognitive conflict-based teaching materials. The distribution of students' conceptual understanding in the experimental and control groups is presented in Table 2.

Table 2. Distribution of Students' Conceptual Understanding in the Pretest and Posttest

Conceptual Understanding Category	Experimental Group		Control Group	
	Pretest (%)	Posttest (%)	Pretest (%)	Posttest (%)
CCU	26	80	27	50
LCU	34	12	33	19
M	40	8	40	31

Based on Table 2, the distribution of students' conceptual understanding in the pretest was relatively similar between the experimental and control groups. The percentage of students classified as having misconceptions (M) was the highest in both groups (40%), whereas only 26% of students in the experimental group and 27% in the control group demonstrated correct conceptual understanding (CCU). These findings indicate that most students experienced difficulties in understanding light-wave concepts before instruction. Following the implementation of the learning intervention, the percentage of students with correct conceptual understanding in the experimental group increased substantially from 26% to 80%, while the percentage of misconceptions decreased from 40% to 8%. In contrast, the control group showed a more modest improvement, with the percentage of correct conceptual understanding increasing from 27% to 50% and misconceptions decreasing from 40% to 31%. hese descriptive findings suggest that students who learned using AR-integrated cognitive conflict-based teaching materials achieved greater conceptual improvement than those who received conventional instruction.

Although the percentage distributions presented in Table 4 indicate differences in students' conceptual understanding between the experimental and control groups, further analysis is required to describe the characteristics of the posttest data more comprehensively. Descriptive statistics were therefore calculated to summarize students' conceptual understanding in terms of central tendency and data dispersion for each conceptual understanding category. These descriptive measures provide a clearer overview of the differences between the two groups and serve as preliminary evidence before hypothesis testing is conducted. The results of the descriptive statistical analysis are presented in Table 3.

Table 3. Descriptive Statistics of Conceptual Understanding

Conceptual Understanding Category	Group	N	Mean	SD	Median	Minimum	Maximum
CCU	Experimental	36	8.03	1.08	8.00	6	10
	Control	33	4.97	1.13	5.00	4	7
LCU	Experimental	36	1.17	0.91	1.00	0	3
	Control	33	1.94	1.64	2.00	0	5
M	Experimental	36	0.83	1.03	0.50	0	4
	Control	33	3.09	1.88	3.00	0	6

Based on Table 3, the descriptive statistics indicate a clear difference in students' conceptual understanding between the experimental and control groups following the learning intervention. Overall, students in the experimental group demonstrated better conceptual understanding than those in the control group, as reflected by the higher level of correct conceptual understanding and the lower occurrence of misconceptions. This pattern suggests that students who learned using AR-integrated cognitive conflict-based teaching materials were more successful in reconstructing their initial conceptions into scientifically accepted concepts. In contrast, students who received conventional instruction still tended to retain incomplete or incorrect conceptual understanding of light-wave concepts. These descriptive findings are consistent with the percentage distributions presented in Table 4 and provide preliminary evidence that the developed teaching materials facilitated more effective conceptual learning.

Although the descriptive results indicate noticeable differences between the experimental and control groups, inferential statistical analysis was conducted to determine whether these differences were statistically significant. Prior to hypothesis testing, the posttest data were examined for normality using the Shapiro–Wilk test. The analysis showed significance values below 0.05 for all datasets, indicating that the posttest data were not normally distributed. Therefore, the nonparametric Mann–Whitney U test was employed to compare students' conceptual understanding between the experimental and control groups. The results of the analysis are presented in Table 4.

Table 4. Results of the Mann–Whitney U Test for Conceptual Understanding

Conceptual Understanding Category	Mann–Whitney U	Wilcoxon W	Z	Sig.(2-tailed)	Decision
CCU	42.500	603.500	-6.728	0.000	H_0 Rejected
LCU	444.000	1110.000	-1.863	0.062	H_0 Accepted
M	176.500	842.500	-5.129	0.000	H_0 Rejected

Based on Table 4, the significance values obtained for the categories of correct conceptual understanding and misconceptions were both 0.000. Since these values were below the 0.05 significance threshold, significant differences were identified between the experimental and control groups for both categories. In contrast, the category of lack of conceptual understanding produced a significance value of 0.062, indicating comparable results between the two groups. Overall, the Mann–Whitney U analysis indicates that the implementation of AR-integrated cognitive conflict-based teaching materials influenced students' conceptual understanding. This influence is reflected in the greater proportion of students demonstrating correct conceptual understanding and the smaller proportion exhibiting misconceptions in the experimental group relative to the control group.

Besides conceptual understanding, students' self-efficacy was also evaluated following the learning intervention. Self-efficacy was assessed using a questionnaire comprising three dimensions: confidence in performing learning tasks, confidence in attaining learning objectives, and confidence in dealing with learning challenges. The analysis compared students' self-efficacy between the experimental group, which learned using AR-integrated cognitive conflict-based teaching materials, and the control group, which received conventional instruction supported by printed textbooks. The distribution of students' self-efficacy in both groups is presented in Table 5.

Table 5. Distribution of Self-Efficacy Levels

Self-Efficacy Aspect	Experimental Group			Control Group		
	Low	Moderate	High	Low	Moderate	High
Confidence in performing learning tasks	0.0%	3.4%	96.6%	33.3%	42.4%	24.2%
Confidence in attaining learning objectives	0.0%	3.4%	96.6%	51.5%	30.3%	18.2%
Confidence in dealing with challenges encountered	0.0%	6.9%	93.1%	54.5%	30.3%	15.2%

Based on Table 5, distinct differences in the distribution of students' self-efficacy were observed between the experimental and control groups across all measured dimensions. Overall, students who learned using AR-integrated cognitive conflict-based teaching materials tended to be classified in the high self-efficacy category, whereas students in the control group were predominantly classified in the low and moderate categories. This pattern indicates that the learning experiences provided through the developed teaching materials were more effective in fostering students' confidence in performing learning tasks, attaining learning objectives, and dealing with learning challenges. In contrast, students who received conventional instruction supported by printed textbooks generally demonstrated lower levels of confidence across the three measured dimensions. These descriptive findings suggest that the integration of cognitive conflict strategies and AR technology contributed positively to students' self-efficacy, although inferential statistical analysis was required to determine whether these differences were statistically significant.

Before testing the research hypothesis, assumption testing was conducted to examine the normality and homogeneity of the self-efficacy data. The normality analysis indicated significance values of 0.323 for the experimental group and 0.969 for the control group, showing that the self-efficacy scores in both groups were normally distributed. In addition, Levene's test yielded a significance value of 0.644, indicating homogeneous variances between the two groups. Since both statistical assumptions were satisfied, differences in students' self-efficacy were analyzed using the Independent Samples *t*-test. Descriptive statistics together with the results of the hypothesis test are presented in Table 6.

Table 6. Analysis of Students' Self-Efficacy

Statistical Parameter	Experimental Group	Control Group
N	29	33
Mean	88.17	49.21
Standard deviation	8.611	8.901
Minimum	64	26
Maximum	108	70
t-value	17.459	
Degrees of freedom (df)	60	
Sig. (2-tailed)	0.000	
Mean Difference	38.960	
Decision	H_0 Rejected	

Based on Table 6, the descriptive statistics indicate that students in the experimental group achieved substantially higher self-efficacy scores than those in the control group after the learning intervention. This finding is reflected in the higher mean self-efficacy score of the experimental group, suggesting that students who learned using AR-integrated cognitive conflict-based teaching materials developed stronger confidence in their learning abilities. The Independent Samples *t*-test further confirmed that the difference between the two groups was statistically significant ($t(60) = 17.459$, $p < .001$). The mean difference of 38.960 indicates that the experimental group consistently outperformed the control group in terms of self-efficacy. These findings are consistent with the descriptive distribution presented in Table 5, in which most students in the experimental group were classified in the high self-efficacy category across all measured dimensions. Overall, the results demonstrate that AR-integrated cognitive conflict-based teaching materials were effective in enhancing students' self-efficacy compared with conventional instruction supported by printed textbooks.

Discussion

The findings of this study demonstrate that AR-integrated cognitive conflict-based teaching materials effectively improved students' conceptual understanding of light waves compared with conventional instruction. Descriptive analysis showed that students in the experimental group achieved higher correct conceptual understanding and lower misconception scores than those in the control group after the learning intervention. These findings were supported by the Mann–Whitney U test, which confirmed significant differences in correct conceptual understanding and misconceptions between the two groups. In contrast, no significant difference was found in the category of lack of conceptual understanding. This finding suggests that the learning intervention primarily promoted conceptual reconstruction by transforming students' misconceptions into scientifically accepted concepts, rather than substantially changing students who simply had insufficient conceptual knowledge. The results indicate that the developed teaching materials not only facilitated conceptual understanding but also reduced students' misconceptions regarding light-wave concepts. Overall, the findings provide empirical evidence that integrating cognitive conflict with AR effectively promotes conceptual change.

The improvement in students' conceptual understanding can be explained by the implementation of the Cognitive Conflict-Based Learning Model embedded within the teaching materials. According to Mufit and Fauzan (2019), the model consists of four instructional stages: activation of preconceptions and misconceptions, presentation of cognitive conflict, concept and equation discovery, and reflection. During the activation stage, students were encouraged to express their prior understanding of light-wave concepts. This stage is essential because students frequently possess prior conceptions that differ from scientifically accepted explanations (Mufit et al., 2019). When students were subsequently confronted with discrepant phenomena, cognitive conflict emerged as they realized that their existing conceptions could not adequately explain the observed evidence. This condition encouraged students to reconsider their prior understanding and search for more scientifically acceptable explanations.

The conceptual reconstruction observed in this study suggests that students gradually replaced their initial misconceptions with scientifically accepted concepts through the learning process. Cognitive conflict functions as a trigger for conceptual change rather than directly eliminating misconceptions. Through cognitive conflict, students become dissatisfied with their initial conceptions and gradually reconstruct their understanding until scientifically accepted concepts are achieved (Makhrus & Busyairi, 2022), This mechanism is also consistent with Piaget's constructivist theory, which explains learning through the processes of assimilation, accommodation, and equilibration (Pakpahan & Saragih, 2022). During the concept discovery and reflection stages, students actively evaluated their previous conceptions, interpreted scientific evidence, and reconstructed their understanding based on more appropriate explanations. Consequently, learning became an active knowledge-construction process that promoted conceptual understanding while reducing misconceptions. These findings reinforce previous studies reporting that cognitive conflict-based learning effectively facilitates conceptual change and improves students' conceptual understanding (Mufit et al., 2023).

The effectiveness of the teaching materials was further strengthened by the integration of Augmented Reality (AR), which enabled abstract light-wave phenomena to be visualized through interactive three-dimensional representations. Unlike conventional two-dimensional illustrations, AR allows students to observe virtual objects from multiple perspectives and repeatedly explore dynamic phenomena, making abstract concepts easier to understand (Ropawandi et al., 2022). This interactive visualization complements the cognitive conflict process by allowing students to compare their initial predictions with observable scientific phenomena. Consequently, students actively construct knowledge through observation, exploration, and discussion rather than passively receiving information. This learning environment supports deeper conceptual understanding.

The findings of this study are consistent with previous research demonstrating the effectiveness of AR in physics learning. Imohimi (2025) reported that AR enhances conceptual understanding by providing interactive and contextual learning experiences that promote deeper understanding of complex STEM concepts. Similarly, the systematic literature review conducted by Sebastian and Kuswanto (2024) concluded that AR consistently improves students' conceptual understanding through interactive three-dimensional visualization of abstract physics concepts. Empirical studies by Hidayah et al. (2025), Khoiriyah et al. (2025) and Ropawandi et al. (2022) also reported that AR-assisted learning significantly improves students' conceptual understanding by helping them visualize scientific phenomena that are difficult to observe directly. Compared with these previous studies, the present study extends existing evidence by integrating AR within cognitive conflict-based teaching materials rather than employing AR solely as a visualization medium. This integration enables AR not only to facilitate visualization of abstract concepts but also to strengthen the conceptual change process initiated through cognitive conflict, resulting in improved conceptual understanding while reducing students' misconceptions.

Beyond improving students' conceptual understanding, the findings of this study also demonstrate that AR-integrated cognitive conflict-based teaching materials effectively enhanced students' self-efficacy. Descriptive statistics showed that the experimental group achieved substantially higher self-efficacy scores than the control group after the learning intervention. This finding was supported by the distribution of self-efficacy levels, in which most students in the experimental group were categorized in the high self-efficacy category across all measured aspects, whereas students in the control group were predominantly classified in the low and moderate categories. The Independent Samples *t*-test further confirmed a statistically significant difference in self-efficacy between the two groups. These findings indicate that integrating cognitive conflict strategies with AR technology supports not only students' conceptual understanding but also their confidence in learning physics.

The improvement in students' self-efficacy observed in this study is likely associated with the meaningful learning experiences provided throughout the instructional process. Students who successfully complete learning tasks and overcome academic challenges tend to develop stronger beliefs in their own capabilities. This process is consistent with the social cognitive theory, which identifies mastery experience as the most influential source of self-efficacy (Bandura, 1997). Successful learning experiences have also been recognized as an important source of self-efficacy because they strengthen students' confidence in accomplishing similar tasks in the future Ugwuanyi et al. (2023). In the present study, students actively identified their initial conceptions, confronted cognitive conflict, explored AR visualizations, discussed scientific explanations, and successfully reconstructed their understanding of light-wave concepts. These meaningful learning experiences likely strengthened students' confidence in their ability to understand abstract physics concepts and solve related learning tasks.

AR also contributed to the development of students' self-efficacy by creating a more engaging learning environment. Interactive three-dimensional visualizations enabled students to explore abstract light-wave phenomena more easily, reducing uncertainty and encouraging active participation. According to Ropawandi et al. (2022), AR promotes meaningful learning by allowing students to explore scientific phenomena, test predictions, and construct their own understanding through interaction with virtual objects. Such learning experiences fostered both students' conceptual understanding and self-efficacy during physics learning.

The present findings are consistent with previous studies reporting positive effects of AR-supported learning on students' self-efficacy. Cai et al. (2021) found that students who learned through AR-assisted instruction demonstrated significantly higher self-efficacy than those receiving conventional instruction. Similar findings were reported by Mufit, Dewi, et al. (2025) and Mufit, Abdilah, et al. (2025), who found that AR-integrated cognitive conflict learning strengthened students' confidence in understanding and solving physics problems. Collectively, these studies support the present findings that integrating cognitive conflict with AR creates meaningful learning experiences that contribute to stronger self-efficacy.

The contribution of this study lies not merely in demonstrating the effectiveness of AR-integrated cognitive conflict-based teaching materials, but also in showing how the integration of cognitive conflict pedagogy and AR visualization creates meaningful learning experiences that simultaneously promote students' conceptual understanding and self-efficacy. Unlike previous studies that have primarily examined the effects of cognitive conflict or AR separately, this study provides empirical evidence that combining these two approaches within teaching materials can support both cognitive and affective learning outcomes. The findings further suggest that technology-supported conceptual change offers a promising instructional approach for facilitating the learning of abstract physics concepts while strengthening students' confidence in their learning abilities.

CONCLUSION

This study concludes that AR-integrated cognitive conflict-based teaching materials effectively enhance both conceptual understanding and self-efficacy in learning abstract light-wave concepts. The findings indicate that integrating cognitive conflict pedagogy with AR visualization facilitates meaningful conceptual reconstruction while strengthening students' confidence in learning physics. More importantly, this study extends current knowledge by demonstrating that combining conceptual change pedagogy and immersive visualization within a single teaching material can simultaneously promote cognitive and affective learning outcomes. These findings contribute to the advancement of physics education by providing empirical support for the development of technology-enhanced teaching materials that facilitate meaningful learning of abstract scientific concepts.

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