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Impacts of STEM-integrated Cognitive Conflict-based Augmented Reality as a 21st Century Learning Strategy on Student Learning Motivation

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ABSTRACT

Physics learning often faces challenges in terms of low student motivation, especially in abstract materials such as Newton's law of gravity and Kepler's law. Based on observations at SMAN 3 Batusangkar, it was found that student motivation was still in the moderate to low category, which had an impact on concept understanding and learning participation. To answer this problem, Augmented Reality (AR) based teaching materials based on STEM integrated cognitive conflict learning model were developed. This study aims to determine the effectiveness in increasing student learning motivation. Using pre-experimental method with One-Group Pretest-Posttest design, this study involved 30 students of class XI F3 as subjects. The research instrument was an ARCS model learning motivation questionnaire. The results showed a significant increase in student learning motivation from an average score of 2.50 to 3.84. The Wilcoxon test resulted in a significance of 0.000 (<0.05), which indicates the effectiveness of teaching materials in increasing student motivation. In conclusion, AR teaching materials based on cognitive conflict and STEM approach are effective in increasing learning motivation on Newton's law of gravity material. This research is useful for the development of innovative learning media, improving the quality of the learning process, and as a reference for the development of technology-based media in science education.

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INTRODUCTION

Education is the main foundation in shaping individuals and society. Along with the times and technological advances, the education paradigm has undergone a significant transformation (Wajdi, 2023). 21st century education demands mastery of skills, knowledge, and attitudes that are in line with current and future challenges (Asrizal & Festiyed, 2020; Kemendikbud, 2017; Trilling, 2009). The change in the education paradigm is characterized by a shift from a teacher-centered approach to student-oriented learning, and supported by active, collaborative, and contextual learning strategies based on information and communication technology (ICT) to create an interactive, dynamic, and relevant learning process with the times (Zhao, 2010; Fadillah, 2024). Therefore, school learning needs to utilize digital technology and use student-centered learning models.

One of the technologies that can be applied in learning is Augmented Reality or better known as AR. Augmented Reality technology is able to unite virtual objects with the real environment in real-time, thus making the learning process more interactive and interesting (Mufit et al., 2023; Adryansyah et al., 2023). The utilization of Augmented Reality through visual content such as images and videos in the learning process can make learning more interesting, flexible, and interactive (Mufit et al., 2023; Bakri et al., 2019). This not only enriches the learning experience, but also has the potential to significantly increase student motivation and engagement.

Learning motivation is an important key to encourage students to be active, independent, and have high curiosity in the learning process (Amalia et al., 2024) . Student learning motivation is important for educational progress (Azmi et al., 2021). Learning motivation is an encouragement that comes from within students and the surrounding environment to achieve learning goals (Elvianasti et al., 2022). There are four main aspects of motivation, namely attention, relevance, confidence, and satisfaction (Keller, 2010). These aspects play an important role in maintaining student interest and engagement in learning, without strong motivation, 21st century learning goals that emphasize creativity, collaboration, communication, and critical thinking will be difficult to achieve.

Physics as a branch of natural science that studies natural phenomena in the surrounding environment is often considered difficult by students because of its abstract concepts and is dominated by complex mathematical formulas, giving rise to the perception that physics is a challenging lesson to understand (Purwanto et al., 2019; Mufit, 2018). To overcome these challenges, an effective learning model such as cognitive conflict-based learning is needed. This model helps to remediate students' misconceptions by bringing up discrepancies between their initial understanding and scientific facts, thus encouraging students to reconstruct concepts independently (Pratama, et al, 2021). The application of cognitive conflict-based learning models is a relevant strategy to improve students' understanding of abstract physics concepts (Ilahi et al., 2021). By presenting situations that cause conflict between students' prior knowledge and actual scientific phenomena, this model not only helps overcome misconceptions, but also encourages students' active involvement in building deeper and more meaningful understanding.

Research by Mariyadi and Idam R.W (2023) revealed that 66.7% of students had misconceptions about gravitational force. In addition, Hikmah's research (2024) showed that 56% of students still did not understand the concept of particle dynamics, including gravitational force. This shows students' low understanding of the concept of Newton's Law of Gravity. As a result, the learning process becomes less meaningful and boring so that students' learning motivation becomes low. The initial test conducted at SMAN 3 Batusangkar found that students' learning motivation was still relatively low, as shown in Table 1.

Table 1. Percentage Results of Student Motivation

Criteria	Motivation Indicator			
	Attention	Relevance	Confidence	Satisfaction
	Number of students (%)	Number of students (%)	Number of students (%)	Number of students (%)
Low	24 (80%)	21 (70%)	27 (90%)	18(60%)
Medium	6 (20%)	9 (30%)	3 (10%)	11 (37%)
High	0 (0%)	0 (0%)	0 (0%)	1 (3%)

Low learning motivation is reflected in the lack of interest, attention, and active participation of students in learning (Nizar et al., 2021). This is caused by teaching materials that are monotonous and less contextualized. The teaching materials used have not been able to bridge the understanding of abstract concepts visually (Osadchyi et al., 2021; Djarwo et al., 2025). Motivation plays a crucial role in driving students' willingness to engage with learning materials and persist in overcoming academic challenges. Therefore, it is necessary to apply a more interesting and interactive approach.

One solution that can be used is Augmented Reality (AR) technology in physics learning. This technology can display interesting and real-looking 3-dimensional objects or simulations (Mufit & Dhanil, 2024). That way, students can more easily understand difficult concepts such as force and motion. AR also makes lessons more interesting and fun for students. In addition, AR provides a learning experience that involves many senses, such as seeing, hearing, and sometimes touching, thus helping students remember the material more easily. With more exciting and real learning, AR not only helps students understand lessons, but also makes them more enthusiastic and active in class.

In addition to AR, learning models also need to be considered, one of which is by using a cognitive conflict model. This model triggers students to realize the discrepancy between their prior knowledge and the scientific facts displayed (Mufit & Dhanil, 2024). The syntax of the cognitive conflict model consists of four main stages. First, preconception activation, which explores students' prior knowledge to identify misconceptions. Second, cognitive conflict presentation, where students are shown phenomena or information that contradicts their preconceptions so as to cause conflict. Third, concept discovery, where students are guided to explore and find the correct scientific concepts. Fourth, reflection and concept reorganization, where students reflect on their understanding and reorganize concepts according to the correct science (Mufit, 2018). This process encourages deeper conceptual change. Thus, students' misconceptions can be corrected scientifically. This process encourages deeper conceptual changes. Thus, students' misconceptions can be corrected scientifically.

The cognitive conflict model with AR technology will be stronger if it is associated with the STEM approach. The STEM approach highlights the integration of science, technology, engineering, and mathematics to solve real-world problems (Asrizal et al., 2023; Alkhabra et al., 2023). The integration of cognitive conflict model with Augmented Reality technology and STEM approach makes learning more interesting and meaningful. AR helps visualize abstract concepts in a real way so that cognitive conflict is easier to generate. The STEM approach supports this by emphasizing the integration of science, technology, engineering and mathematics in solving real problems. Students are trained to think critically, creatively, collaboratively and innovatively-aligned with 21st century skills. This combination not only improves concept understanding, but also shapes competencies relevant to future needs.

AR based on STEM integrated cognitive conflict has been developed by previous researchers and has been validated by experts. The validation results show that the teaching materials are very feasible to use in physics learning (Mufit et al., 2025). AR developed based on the syntax of the cognitive conflict model is made to help students learn in a more interesting and understandable way. By using markers, students can see 3D images of physics concepts directly in front of them, such as force simulation or object movement. This application follows the steps of the cognitive conflict model, so that students are directed to go through learning stages ranging from activation of misconceptions and preconceptions, seeing conflicts from the phenomena presented, discovering new concepts, to reflecting. Each question in the application is adapted to these steps. In addition, there is also a virtual laboratory experiment feature, so students can conduct experiments digitally even without physical tools. This makes learning more flexible and engaging.

The AR in this app also features learning from a STEM perspective. From the science side, students learn the basic applicable concepts; from the technology side, they interact with AR-based digital devices; from the engineering side, they understand the application of concepts to solve problems and design solutions; and from the math side, they perform relevant calculations or data analysis. This integration fosters cross-disciplinary understanding and prepares students to be active, critical, and adaptive learners according to the demands of the digital era. However, the effectiveness of this teaching material has not been proven empirically in the classroom and further research needs to be done to test its impact. Based on this background, the research problem can be formulated, namely how the effectiveness of STEM-integrated cognitive conflict-based Augmented Reality on student motivation? This study aims to test the effectiveness of STEM-integrated cognitive conflict-based AR teaching materials on Newton's Law of Gravity material.

METHODS

The research method used in this study is the method of pre-experimental designs . This research method is a form of experimentation that is not yet real because there are still outside variables that affect the treatment that cannot be fully controlled. The research design used is One-Group Pretest-Posttest Design. This study only uses one class that samples consisting of 30 students. The sample class was given treatment with Augmented Reality based on STEM integrated cognitive conflict model.

Early learning activities students are given an initial test *(*pretest*)* to measure the initial ability of students, after which the class is given treatment using Augmented Reality based on STEM integrated cognitive conflict. After treatment, the class was given a final test *(*posttest*)* to determine changes in student motivation. This research design is presented in Table 2.

Table 2. Research Design

Pretest	Treatment	Posttest
O_1	X	O_2

Source: Sugiyono (2013)

Description
O_1 : Initial test score
O_2 : Final test score
X : Treatment using Augmented Reality based on STEM integrated cognitive conflict model

The research procedures are systematic steps undertaken to collect data and address the research questions. This study was conducted through three main phases: the preparation stage, the implementation stage, and the completion stage. In the preparation stage, the researchers selected the school and scheduled the research timeline, prepared official permission letters, determined the population and sample, and developed the research instruments. The implementation stage involved conducting the study in one sample class that received treatment using STEM-integrated cognitive conflict-based Augmented Reality media. This treatment was intended to observe its effect on students' learning motivation. The final phase, the completion stage, included data collection, data processing and analysis, as well as a discussion of the findings obtained during the research. The discussion aimed to interpret the results and evaluate the effectiveness of the implemented learning strategy. This stage concluded with drawing final conclusions from the entire research process.

According to Arikunto (2014), population is the overall research subject. In line with that, Sugiyono (2013) states that population is a generalization area consisting of objects or subjects that have certain qualities and characteristics set by researchers to study and draw conclusions.

In this study, the affordable population that became the object of study was all students of class XI Phase F (IPA-Physics) at SMAN 3 Batusangkar registered in the 2024/2025 school year, consisting of three classes. All students in this population have chosen specialization in physics subjects, so they are considered relevant to be the subject of research that focuses on learning physics concepts using technology-based media. According to Arikunto (2014), a sample is a representative of the population under study. In line with that, Sugiyono (2013) states that the sample is part of the number and characteristics of the population. In this study, sampling was carried out using purposive sampling technique. According to Sugiyono (2013), purposive sampling is a sampling technique based on certain considerations or criteria.

Based on the results of interviews with physics teachers, obtained information that class XI Phase F (IPA-Physics) consists of three classes. The placement of students in class XI is categorized based on the specialization subject group chosen by the students. The selection of samples was based on the consideration of the subject teacher who grouped classes with low category scores in physics subjects, which were reviewed from the results of students' daily assessments. The class selected as the sample was class XI Phase F 3, which consisted of 30 students, with details of 27 male students and 3 female students.

At the assessment stage, data collection was conducted to evaluate the effectiveness of the research product. The data collection technique involved written tests aimed at determining the final outcomes of the treatment, which utilized Augmented Reality based on STEM-integrated cognitive conflict in learning activities. This assessment consisted of a Pretest and a Posttest.

Tabel 3. Data Collection Technique

Data Type	Research Instruments	Data Collection Technique
Motivation Questionnaire	Student motivation statement items according to motivation indicators	Used before and after learning

Research instruments are measuring instruments or guidelines used to collect research data. The learning motivation questionnaire instrument referred from a book entitled "*Motivational Design for Learning and Performance: The ARCS Model Approach*" which has been tested and validated to see changes in student learning motivation. The motivation questionnaire consists of 35 statements.

After the experiment was conducted, data was obtained in the form of pretest and posttest scores. The data was tested for prerequisites and hypothesis testing of mean differences. Before hypothesis testing, a normality test with the Shapiro Wilk test was performed. This test is conducted to determine whether the data is parametric or non-parametric. Normality tests and hypothesis tests were carried out using the SPSS version 25.0.0 application. The significant level used in the normality test and hypothesis test is 0.05.

RESULTS AND DISCUSSION

Result

Results of Analysis of each Motivation Indicator

A comparison of the average motivation of students before and after treatment can be seen in Table 4. The table shows that all aspects of motivation have increased, both in terms of average scores and categories. Before the treatment, most aspects were in the medium category, and self-confidence was in the low category. After the treatment, all aspects increased to the high category. This finding indicates that the treatment was effective in increasing students' learning motivation.

Table 4. Comparison of Average Motivation of Pre-Treatment and Post-Treatment Students

	Pre-treatment		Post-treatment	
	Average	Category	Average	Category
Attention	2.986	Medium	3.814	High
Relevance	2.404	Medium	3.892	High
Confidence	2.037	Low	3.807	High
Satisfaction	2.611	Medium	3.833	High
Motivation	2.503	Medium	3.845	High

Table 4 shows significant changes in the average student motivation before and after treatment based on the four main indicators of motivation according to the ARCS model (Attention, Relevance, Confidence, Satisfaction). Before the treatment, students' motivation was generally in the moderate category, with an overall mean score of 2.503. Especially in the confidence indicator, students were in the low category 2.037, which indicated that they were not confident in their ability to understand physics material, especially Newton's law of gravity and Kepler's Law.

After treatment in the form of cognitive conflict-based learning integrated with STEM approach and Augmented Reality (AR) based media, there was a very significant increase in all indicators. The attention value increased from 2.986 to 3.814, indicating that learning succeeded in attracting students' attention more effectively. The relevance indicator increased from 2.404 to 3.892, reflecting that students began to see the relevance of the material to their real life or future. The most striking increase occurred in the confidence indicator, from 2.037 to 3.807, indicating that the treatment was very effective in building students' confidence in the subject matter. The satisfaction indicator also increased from 2.611 to 3.833, indicating that students were satisfied with the learning process and results.

The average student motivation increased from a moderate score of 2.503 to a high score of 3.845. This shows strong evidence that the treatment provided was effective in enhancing overall learning motivation. The integration of cognitive conflict, the STEM approach, and AR technology contributed to this improvement. These elements created a learning experience that was more engaging, meaningful, and significantly boosted students' confidence.

The analysis of differences in student motivation before and after treatment is shown in Table 5. This table shows the percentage increase in each motivation indicator after students get the learning treatment. The indicators analyzed include attention, relevance, confidence, satisfaction, and overall motivation. This data provides a more measurable picture of the impact of the treatment on increasing students' learning motivation.

Table 5. Results of Percentage Analysis of Differences in Pre-Treatment and Post-Treatment Student Motivation

	Pre-treatment	Post-treatment	Percentage Difference
Attention	2.986	3.814	27.72 %
Relevance	2.404	3.892	61.89 %
Confidence	2.037	3.807	86.89 %
Satisfaction	2.611	3.833	46.80 %
Motivation	2.503	3.845	53.61 %

Based on Table 5, it can be seen that all indicators of student motivation have increased after being given treatment using Augmented Reality based on STEM integrated cognitive conflict. The most significant increase occurred in the aspect of self-confidence, with a percentage of 86.89%, which shows that this learning approach is very effective in fostering student confidence in the learning process. Followed by the relevance indicator which increased by 61.89%, indicating that students felt the learning material was more meaningful and relevant to real life. Learning satisfaction also experienced a fairly high increase of 46.80%, reflecting that students feel more happy and satisfied with the learning method applied. Meanwhile, the attention indicator showed the lowest increase of 27.72%, although it still showed improvement. Overall, students' motivation level increased by 53.61%, confirming that the instructional approach used had an overall positive impact on increasing students' learning motivation.

Two Mean Comparison Test Results

Before conducting hypothesis testing on student learning motivation, it is necessary to conduct a normality test to determine whether the data is normally distributed. The normality test aims to determine the right type of statistical test in comparing pre-treatment and post-treatment data. Hypothesis testing itself is a statistical procedure used to test the truth of a conjecture or claim based on sample data. The purpose of hypothesis testing is to determine whether there is a significant difference between two conditions or treatments, in this case before and after the application of cognitive conflict-based learning integrated with STEM and AR technology. The results of the normality test of student motivation are shown in Table 6 below.

Tabel 6. Normality Test Results of Student Motivation

	Statistic	Sig.	Skwness	Kurtosis	Description
Pre-treatment	0.895	0.006	0.427	0.833	Not Normal
Post - treatment	0.970	0.540	0.427	0.833	Normal

Table 6 shows that the data obtained pre-treatment is not normally distributed with a normality result of 0.006. This significant result (Sig. < 0.05) indicates that there is a difference in the normality of the sample, which then interprets the data distribution as abnormal. While post-treatment, the normality result of significance is 0.540, this states that (Sig. > 0.05) so that the data is normally distributed. The results of the normality test showed that one of the data was not normally distributed.

Table 7 presents the results of the Wilcoxon Rank Test analysis used to evaluate the difference between pre-treatment and post-treatment scores. This test was chosen because the data was not normally distributed, thus requiring a non-parametric test. The results of the analysis showed a significant difference between the two conditions. This can be seen from the absence of negative ratings and only positive ratings with an average rating of 15.50 and a total rating of 465.00.

Table 7. Wilcoxon Test Rank Analysis Results

		N	Mean Rank	Sum of Ranks
Post-treatment - Pre-treatment	Negative Ranks	0[a]	0.00	0.00
	Positive Ranks	30[b]	15.50	465.00
	Ties	0[c]		
	Total	30		

Based on the results of the Wilcoxon Rank Test analysis presented in Table 7, it can be seen that no negative rank values appeared (N=0), indicating that none of the participants experienced a decrease in learning motivation after the treatment. Instead, all participants (N=30) experienced a significant increase in learning motivation, as seen from the number of positive ratings (N=30). The mean value of positive ratings was 15.50, indicating a consistent increase in motivation among all participants. The total number of positive ratings obtained was 465.00, further confirming these results. The decision to use the Wilcoxon Rank Test was appropriate as the data was not normally distributed, making non-parametric methods a valid option. This increase in motivation can be attributed to the integration of STEM-based learning enriched with cognitive conflict approach and Augmented Reality technology. This finding shows that the intervention provided can be effectively applied in increasing students' learning motivation. The conclusion from this data is that the use of innovative technology based on hands-on experience has great potential in supporting more meaningful and learner-centered learning.

The results of the Wilcoxon test to analyze the difference between post-treatment and pre-treatment scores can be seen in Table 8. This test was conducted to evaluate the significance of the changes that occurred after the treatment. Z scores and significance values are presented to indicate the presence of significant differences. Overall, the results of this analysis help support the findings obtained from the previous Table 8.

Table 8. Wilcoxon Test Results

Parameters	Value of Parameters
Z	-4.783
Asymp. Sig. (2-tailed)	0.000

Based on the results presented in Table 8, the Wilcoxon test yielded a Z value of 4.783, which is higher than the critical value of 1.645. This high Z value indicates that the intervention had a significant impact on the measured variable. The significance value (Sig. = 0.000) is below the conventional threshold of 0.05, which further supports the rejection of the null hypothesis $\mathbf{H_0}$ and acceptance of the alternative hypothesis $\mathbf{H_1}$. This finding indicates that there was a statistically significant difference in students' motivation before and after the treatment was administered. The positive Z value indicates that STEM-integrated cognitive conflict-based Augmented Reality causes an increase in motivation. This suggests that the applied learning model is not only innovative but also effective in engaging students and fostering meaningful learning experiences. The use of technology in conjunction with the conflict-based learning model provided a dynamic and interactive environment that likely contributed to this positive outcome. Overall, the data underscores the potential for combining advanced technological tools with active learning approaches to increase student motivation and encourage deeper learning.

Discussion

The results showed that the use of Augmented Reality (AR) technology based on cognitive conflict integrated with the STEM approach was able to increase student learning motivation on the material of Newton's Law of Gravity and Kepler's Law. The increase occurred in all indicators of motivation according to the ARCS model (Attention, Relevance, Confidence, Satisfaction) developed by Keller (2010). Augmented Reality (AR) can increase learning motivation because it presents material in a more real, interactive and interesting way. Through 3D visual displays that can be observed from various points of view, students can more easily understand abstract concepts, such as gravitational force or electromagnetism. In addition, AR allows students to interact directly with learning objects, creating an active and fun learning experience that makes them more interested, focused, and less bored during the learning process.

Research by Nizar, Anuar, and Ismail (2021) supports this finding, where the use of AR in learning significantly increases student motivation. AR provides an interactive and engaging learning experience, encouraging students to be more actively exploring the material. In addition, students feel more confident because they can learn independently and receive feedback directly from AR applications, making the learning process feel more personalized and fun. This is in line with the findings of Ibáñez et al. (2020), who show that AR-based learning helps students achieve a state of flow—a state in which students are truly focused and immersed in learning activities. AR also helps balance the difficulty level of the material and the student's abilities, as well as provides visual support that makes it easier to understand concepts, so that students feel challenged, emotionally engaged, and satisfied with the learning process.

The STEM approach has also been proven to be able to increase students' motivation and understanding of learning. Research by Alkhabra et al. (2023) shows that the use of AR in STEAM (Science, Technology, Engineering, Arts, and Mathematics) programs creates an engaging, active, and meaningful learning experience. AR helps present abstract concepts visually and interactively, encouraging students to think critically and solve real problems. This increases students' enthusiasm, curiosity, and engagement, as they not only receive information, but also experience and apply it firsthand. Thus, the integration of AR in STEM/STEAM-based learning strengthens conceptual understanding and increases students' intrinsic motivation to keep learning.

In addition to influencing motivation, the STEM approach also plays an important role in improving students' understanding of concepts. STEM relates learning materials to real-life contexts through the integration of science, technology, engineering, and mathematics. Students are directly involved in problem-solving and project-based experiments, making abstract concepts easier to understand. Research by Asrizal et al. (2023) proves that STEM-based digital physics teaching materials significantly increase students' concept comprehension scores compared to conventional learning. This approach also encourages 21st-century critical thinking and literacy skills, which are particularly relevant in the face of the challenges of the Industrial Revolution 4.0.

Research by Emilya (2023) also supports this. In his research entitled "Validity of E-module Based on Cognitive Conflict Integrated Augmented Reality for Improving Students' Physics Science Literacy", it was found that cognitive conflict-based e-modules integrated with AR are not only valid in content, but also effective in increasing student motivation. Interactive visualization through AR helps students understand physical phenomena more realistically, while cognitive conflict is presented through questions and activities that challenge students' misconceptions. This combination makes the learning process more challenging and engaging, and encourages students to understand and correct wrong concepts. As a result, students' intrinsic motivation and curiosity increase significantly.

Overall, this study concludes that learning using cognitive conflict-based AR integrated with STEM approaches has a significant positive impact on students' learning motivation. Increased motivation occurred across all ARCS indicators, with confidence recording the highest increase. This shows that after going through cognitive conflicts resolved through AR-based modeling, students feel more confident to complete tasks and understand the material. Active involvement in STEM-based and integrated cognitive conflict model-based problem-solving allows students to experience the relevance of the material in real life, which further encourages intrinsic motivation. Thus, the use of AR in constructivist learning not only improves conceptual understanding, but also strengthens affective dimensions such as students' interest and enthusiasm for learning.

However, this study has some limitations. First, the subjects of the study were limited to one school and one experimental group, with no control group as a comparison. This limits the ability to generalize outcomes and ensures that the increased motivation and understanding of students is entirely due to the treatment given. Second, motivation measurement refers only to the ARCS model, without taking into account other factors such as the student's psychological condition or social support from the surrounding environment. Third, the success of AR implementation is highly dependent on the availability of adequate technology devices and infrastructure in schools. Therefore, follow-up research needs to be carried out with a wider scope, involving control groups, and considering additional variables so that the results obtained are more comprehensive and can be applied widely.

CONCLUSION

Based on the data analysis, it can be concluded that the application of STEM-integrated cognitive conflict-based Augmented Reality (AR) on Newton's Law of Gravity significantly enhances students' learning motivation. The integration of STEM encourages students to connect scientific concepts with real-world contexts, while the cognitive conflict approach stimulates curiosity and deeper understanding through the resolution of misconceptions. Augmented Reality adds an interactive and visual dimension that increases engagement and facilitates conceptual comprehension. This combination creates a learning experience that is not only effective but also enjoyable and meaningful. As a result, students are more motivated, actively involved, and better prepared to master complex physics concepts. Therefore, STEM-integrated cognitive conflict-based AR is recommended as an innovative teaching material. It supports the achievement of learning objectives, fosters critical and creative thinking, and prepares students to face the challenges of the modern scientific and technological era.

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