Augmented Reality-Integrated Teaching Materials on Modern Physics: Enhancing Creativity of Prospective Physics Teachers through Collaborative Problem-Solving

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***Abstract*—Creativity plays a crucial role in higher education, especially in preparing students to face future challenges. This study aims to measure the improvement of creativity in pre-service physics teachers through the implementation of the Collaborative Problem-Solving (CPS) model supported by Augmented Reality (AR) based teaching materials. The teaching materials also include tasks to create mind maps. The study uses a pre-experimental method with a pre-test and post-test control group design, involving 67 students as the sample. Creativity data was collected using the Creativity Self-Assessment (CSA) Questionnaire based on AR-assisted collaborative learning before and after. Data analysis using the Rasch Model and Paired Sample Test showed a significant increase in creativity from pre-test to post-test with $p = 0.001$ after the intervention. Therefore, the implementation of the CPS model supported by AR-integrated teaching materials has proven to be effective in enhancing students' creativity.**

***Keywords*—augmented reality, collaborative problem solving, modern physics, creativity**

I. INTRODUCTION

The teaching of modern physics in higher education institutions still faces many challenges. Key issues include the lack of instructional materials that actively engage students, which leads to a passive learning experience [1], Additionally, the abstract nature of the material complicates teaching methods [2], compounded by low student motivation [3] and a high incidence of misconceptions [4], all of which significantly impact the effectiveness of modern physics education. Interviews with students from the physics education program at a university in Ogan Komering Ulu Timur, South Sumatra, revealed similar challenges. Available teaching materials were ineffective, and teaching methods were still predominantly lecture-based, involving simple presentations and whiteboard use. Ideally, higher education should prioritize active learning models, integrated with collaborative and problem-based learning approaches [5]. Unfortunately, such models are rarely implemented. Furthermore, fostering and developing students' creativity has not been a primary focus, with learning often aimed solely at exam results, which assess cognitive ability but neglect creativity and other essential skills.

Creative thinking has become increasingly important in the face of globalization, increased competition, and technological advancements. In today's digital era, pre-service physics teachers are required to prepare for an uncertain and complex job market, necessitating the development of creative thinking skills essential for future careers. Pre-service teachers also need broad access to information, critical and creative thinking, problem-solving skills, effective communication, optimal use of technology, and collaborative learning abilities. Along with technological literacy, future teachers must learn how to use technology efficiently to create effective learning environments that support the achievement of educational goals [6]. Therefore, creativity needs to be instilled and nurtured.

Modern physics is a compulsory course for pre-service physics teachers. However, its abstract and mathematical nature often presents challenges in understanding [7]. Modern physics explores the behavior of matter and energy at atomic and subatomic levels, requiring visual media to aid understanding. The study of modern physics addresses phenomena beyond classical physics, providing explanations for phenomena inadequately explained by classical theories. Various instructional media, such as educational videos, Physics Education Technology (PhET) online learning platforms [8], virtual simulations, self-regulated learning-based textbooks [1], virtual laboratory [9] and e-module [4] have been developed to overcome these challenges. In the current educational landscape, technological integration is an inevitable shift driven by the development of Industry 4.0. One promising innovation is mobile learning technology, which supports learning via mobile devices [10]. Since almost everyone today has access to a smartphone, its potential for educational purposes is enormous [11]. However, many students primarily use smartphones for social media access. Therefore, there is an urgent need for the development of effective and efficient digital teaching materials. These materials offer engaging, motivating, and enjoyable learning experiences, leading to new teaching methods that align with the demands of modern education. The development of technology-integrated digital teaching materials for modern physics offers a promising solution to improving the quality of education.

Augmented Reality (AR) is an innovative learning technology with great potential. Augmented Reality aims to help students better understand the material [12]. This technology enables the integration of the real world and the digital world by visualizing objects in digital form [13]. Unfortunately, the use of AR in education is still rare due to time constraints in developing this technology and a lack of understanding about its creation process. However, AR has significant advantages, such as its interactive and real-time nature, making it highly suitable as an educational

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medium [14]. In the context of modern physics education, instructors can utilize AR technology to explain complex and abstract concepts, such as relativity, photon particle properties, the photoelectric effect, the Compton effect, and pair production. These concepts are often difficult to comprehend without the aid of in-depth visualization. AR can visualize objects in 3D in quantum physics [15]. The integration of AR-based digital teaching materials in modern physics is an innovative approach that has the potential to enhance the quality of learning in higher education. In addition to visualizing abstract concepts in 3D, these digital teaching materials can also be equipped with virtual laboratories (virtual labs) to support students' scientific performance. This is particularly important as hands-on laboratory activities are often limited due to a lack of laboratory equipment. AR technology also fosters active student interaction, which can spark creativity [16]. Furthermore, the application of AR in learning has a positive impact on student's academic outcomes, including improved responses, creativity, knowledge, skills, and performance [17].

Efforts to maximize the application of modern physics learning can be achieved by using Augmented Reality (AR)-integrated teaching materials based on the Collaborative Problem-Solving approach (CPS). This CPS model has been highlighted by the Organisation for Economic Cooperation and Development (OECD) as an important model for the 21st century [18, 19]. The CPS-based digital teaching materials can facilitate students in enhancing their problem-solving and creativity skills. According to Sun *et al.* [20] he CPS model consists of four stages: building readiness, problem exploration, interactive collaborative problem-solving, and reflection and evaluation of results. Problem-solving skills are one of the main challenges in science education [21] and creativity is an essential attribute in problem-solving. Therefore, students need to acquire these skills to be well-prepared for competitive careers. Currently, higher education institutions are competing to improve their students' creativity [22]. Creativity can drive students toward academic development, critical thinking, and problem-solving abilities, as well as enhance future economic conditions [23]. In this context, innovation in physics education at the university level needs to be implemented by using AR-integrated modern physics digital teaching materials based on CPS to improve concept understanding, problem-solving, and creativity. Creativity is generally defined as the ability to create something new and useful [24]. The development of creative thinking and creative problem-solving is an important aspect of sustainable modern education [24].

Several teaching models have been implemented in modern physics education, including blended learning [25], e-learning [4], Problem-Based Learning [9], guided inquiry [26], and Science, Technology, Engineering, and Mathematics (STEM) with simulations [27], Additionally, modern physics education has incorporated media such as videos [28], PHeT simulations [29, 30], and virtual labs [31, 32]. However, studies indicate a gap in the use of Augmented Reality (AR) in modern physics, with AR still being more commonly developed for basic physics. Therefore, collaboration and integration of AR technology with the Collaborative Problem Solving (CPS) model are considered important. The CPS model was chosen because it can enhance creativity [33]. This innovation offers a new breakthrough for the development of modern physics education technology. Based on this, this study aims to answer the question: "How can the CPS model with AR-integrated teaching materials enhance the creativity of pre-service physics teachers?"

This study aims to examine the impact of the CPS model on enhancing students' creativity. To achieve this goal, we have developed an Augmented Reality (AR)-integrated teaching material equipped with a project task to create mind maps.

The problem-solving approach in this study is based on the needs of modern physics learning, which requires the integration of technology to address students' difficulties in understanding abstract concepts, ineffective teaching methods, and low creativity. To tackle these issues, we have developed digital teaching materials integrated with AR technology. AR can provide a solution to visualize abstract objects so they can be observed realistically. The innovation presented in this study is the combination of the CPS approach with AR-integrated digital teaching materials. CPS is a learning framework that can help students enhance their creativity.

II. Literature Review

A. Augmented Reality

Augmented Reality is a technology that allows digital information to be delivered into the real-world environment through mobile devices, such as smartphones or tablets [33, 34] and can be used interactively [20]. Augmented Reality (AR) is utilized to assist students in understanding materials [16], comprehending concepts that are difficult to grasp through traditional teaching methods [34] and visualizing them as if they were real [35]. AR is an essential tool in physics education [36]. In physics learning, AR has the potential to enhance students' cognitive skills, making them more proficient in solving physics problems and conceptualizing abstract ideas. The use of augmented reality provides opportunities to conduct experiments in situations where physical experiments are not possible, such as in nuclear physics or due to subjective reasons like limited laboratory equipment [34].

B. Collaborative Problem Solving Model

The OECD has highlighted collaborative problem-solving as an essential skill for students in the twenty-first century [19]. Meanwhile, Hesse *et al.* [37] defines CPS as approaching problems responsively by working together and exchanging CPS emphasizes that an individual cannot solve problems alone but rather through group collaboration to achieve goals [38]. The three core competencies of CPS according to OECD. [39] are: 1) building and maintaining shared understanding, 2) taking appropriate actions to solve problems, and 3) building and maintaining team organization.

C. Creativity

Creativity is an essential aspect of science education [33]. Higher education students are at an age where their minds and imaginations are at the peak of creative thinking [24]. The innovations generated by students' creativity can drive future advancements in sustainable development. Scholars view creativity from both specific and holistic perspectives, defining it as either a product or a process [40]. Thus, creativity can be understood as a combination of various skills, knowledge, motivation, and attitudes that individuals use to and original ideas or products.

AR serves as a technology that enables students to explore modern physics phenomena interactively, supported by three-dimensional visuals, animations, and real-time simulations. Meanwhile, CPS is a learning model emphasizing teamwork in solving context-based problems.

In an AR-based environment, students can collaborate to analyze, design solutions, and test hypotheses for given physics problems. AR is a visualization tool and facilitates student interaction in constructing scientific arguments, sharing perspectives, and fostering creativity in problem-solving. Student creativity develops when they face challenges requiring innovative problem-solving approaches. These three concepts can be integrated into an interactive framework, AR as an interactive learning environment that supports the visual and engaging exploration of physics concepts. CPS is a learning model that promotes collaboration in AR-based problem-solving. Student creativity is nurtured through problem-solving challenges and exploration within AR-based learning.

III. Materials and Methods

The method in this research is a pre-experimental design [41] with a one-group pre-test-post-test design with a sample of 67 students. This design was chosen as an initial step to explore creativity and further examine the intervention conducted. Additionally, practicality, lower cost [42], and resource availability were also considerations in determining this research design. The results obtained from this study can serve as a reference or consideration for future research. This design also has limitations, such as lack of control over external variables that can influence research results. This study employed purposive sampling with the consideration that the selected students were enrolled in the Modern Physics course and had never used AR or other technologies in previous physics learning. However, they exhibited a strong curiosity about technology usage. According to Campbell [43] purposive sampling was chosen to ensure that the sample aligns more closely with the research objectives and targets, thereby enhancing the accuracy of the study and the reliability of the data and findings. Before this, the students had not experienced learning using AR technology and the CPS approach in their courses. The design of this study is shown in Fig. 1.

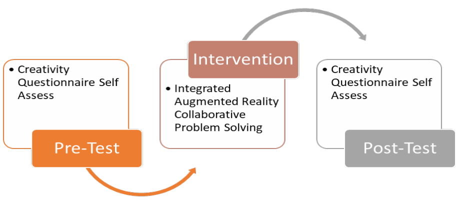


Fig. 1. One group pre-test and post-test design.

During the implementation phase, the students used the previously developed digital teaching materials for modern physics. These teaching materials included modern physics concepts such as theory, virtual labs, AR animations, instructional videos, exercises, and evaluations. The technology used in creating AR is based on the Blender application, which enables the creation of more realistic simulations. The rendering results generated by Blender are then integrated using Assemblr Studio, a platform that allows the combination of visual and interactive elements. In Assemblr Studio, the output is in the form of a marker, which can then be scanned by students using the Assemblr Studio application. This scanning process will display the previously created simulation, allowing students to visualize and interact with virtual objects in a more immersive environment.

Additionally, the teaching materials provided exercises to enhance students' creativity, specifically through mind mapping. This learning process was conducted over five sessions, covering length contraction, time dilation, the photoelectric effect, the Compton effect, and pair production. Mind mapping was used to measure students' creativity before and after using the developed digital teaching materials for modern physics. The AR-integrated modern physics teaching materials are shown in Fig. 2, while the development of creativity is shown in Fig. 3

Fig. 2. Augmented reality display.

Fig. 3. Developing creativity.

The learning model used in this study is CPS [21] which consists of several steps as follows. Students are given a task or project to create a mind map after completing the learning process. The digital application used for creating the mind map is MindMup, which can be accessed online at https://www.mindmup.com. Students can access it for free and use the available features, but with a storage limit of up to

100 KB. To access additional features, a fee is required. The mind map created by the students can be published online and shared with instructors, and it remains publicly accessible for up to 6 months in the free version. Creating a mind map in MindMup aims to assess students' creativity after studying modern physics topics using AR-integrated digital teaching materials and the CPS model. The model syntax is shown in Table 1. Creating mind maps is an effective way to develop ideas and concepts visually. Mind mapping involves creating diagrams or visual representations that link various main ideas to relevant subtopics.

Table 1. Collaborative Problem-Solving Syntax

Step	Activity
Building Readiness	Students understand the learning objectives and the activities/projects to be completed. Students are provided with an explanation of how the project works and the final goal of the project they will undertake. Thus, students can understand what is expected of them and how they can achieve these goals.
Problem Exploration	Students engage in the process of identifying, analyzing, and understanding a problem provided in the teaching materials related to the topic. Students are allowed to study and analyze complex problems, as well as understand the concepts related to the topic. In this way, students can develop their critical and analytical skills in problem-solving.
Interactive Problem-Solving	Students engage in the problem-solving process, which involves active participation from various parties through discussion, collaboration, and direct exchange of ideas. In this process, students can interact with their peers to solve complex problems and develop their ability to work together and communicate effectively. Moreover, this process also enhances students' creativity in developing innovative and effective solutions to problems.
Reflection and Evaluation	Students reflect on and evaluate the learning process that has been carried out. In this stage, students can contemplate and assess what they have learned, as well as identify strengths, weaknesses, and opportunities for improvement in the future. Through this reflection, students can enhance their self-awareness and understand how they can improve their skills and knowledge in relevant areas.

Based on the topic discussed, students are asked to create a mind map with a main topic, such as the photoelectric effect. This mind map is a visual representation of the concepts the students remember after the learning process, ideas about its application in technology, its connection to previous learning, and some new information they have acquired. Students are encouraged to be creative in their presentation by adding images, short videos, or links to relevant web pages.

A. Measurement and Data Analysis

The measurement of students' creativity levels after using the CPS model integrated with AR materials was conducted using the Creativity Questionnaire self-assessment scale, adapted from Lyndi Smith [44] and analyzed for reliability by Hamdan *et al.* [45], Adyasha and Duraipandian [46], validity by Haqqoh [47]. This scale consists of 4 indicators: Generating Ideas, Digging Deeper Into Ideas, Exploring Ideas, and Listening to Your Inner Voice. Each indicator contains several questions, with answers on a 4-point scale: strongly agree, agree, disagree, and strongly disagree. Students were given the questionnaire before and after the learning process, and the data were then analyzed using the Rash model and Jamovi software (T-Test) Result and Discussion.

The Rasch Model is one of the data analysis models used for measurement results, such as questionnaires, ability tests, or other psychometric instruments [48]. his analysis was chosen because of its ability to transform ordinal data (such as Likert scores) into an interval scale that is mathematically more valid. The primary advantage of the Rasch Model lies in its capability to map respondent ability and item difficulty on a single scale that can be directly compared [49]. Jamovi is a statistical software with an intuitive graphical user interface [50]. Additionally, Jamovi provides modules such as snowIRT and linRasch, which allow users to perform Rasch Model analysis quickly and efficiently without requiring expertise in coding or complex syntax [51].

The advantage of using Jamovi with Rasch Model analysis is its ability to generate fit statistics to assess data-model fit [52]. This feature is highly beneficial for researchers in identifying misfitting items or respondents, thereby enabling improvements to the measurement instrument. Furthermore, visualizations such as the Wright Map of respondent ability and item difficulty, generated by Jamovi, provide direct insights into the effectiveness of the instrument used [53]. This enhances the validity and reliability of the measurement.

IV. Result and Discussion

The following are student activities during learning with a CPS model integrated with Augmented Reality. It can be seen that students are very enthusiastic in learning to exchange ideas and collaborate to understand a modern physics concept. Learning activities are shown in Fig. 4.

Next, students discuss and study the concept of Modern Physics with Integrated Augmented Reality Learning Materials shown in Fig. 5.

Fig. 4. Activities student.

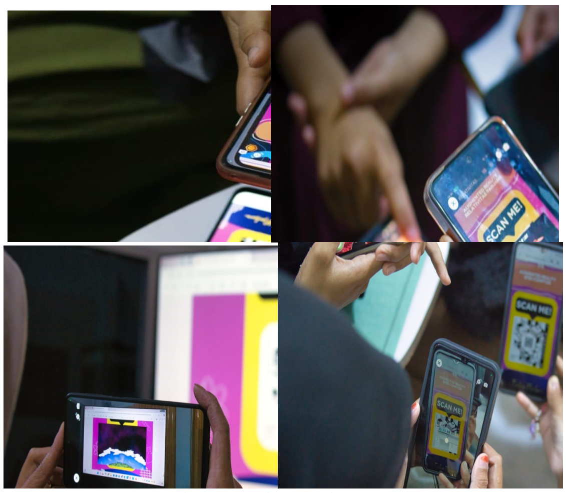


Fig. 5. Students using AR.

A. Creativity Questionnaire Self-Assessment

The results of students' creativity before and after using the CPS model integrated with AR teaching materials were analyzed using the rasch model. The instrument used to measure students' creativity was the creativity questionnaire self-assessment scale, which consists of 4 indicators: generating ideas, digging deeper into ideas, exploring ideas, and listening to your inner voice. Before performing the analysis, the researcher conducted a normality test on the sample used, which was greater than 30, in this case, 67. The results of the analysis are shown in Fig. 6.

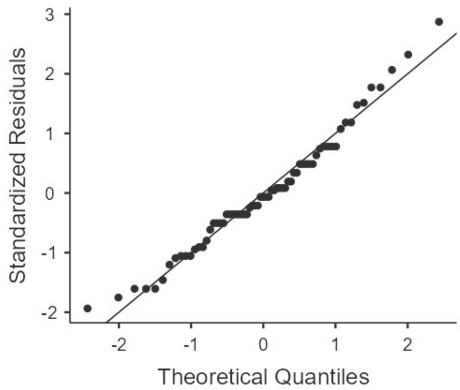


Fig. 6. Data normality test.

Based on Fig. 6, the data points are closely scattered along the diagonal line, indicating that the normality assumption is met, allowing for further analysis. The implementation of the CPS learning model with AR-integrated teaching materials resulted in data on the creativity of pre-service physics teachers before and after using the self-assessment questionnaire.

Table 2. Student creativity results data

Group	N	Mean	SD
Before	67	2.79	0.374
After	67	3.45	0.193

N: Sample Size
SD: Standard deviation

Table 2 shows the difference in the mean scores before and after using the CPS learning model integrated with AR teaching materials. The post-test mean is higher than the pre-test mean. Further analysis of the magnitude of the effect between before and after is shown in Figs. 7–8.

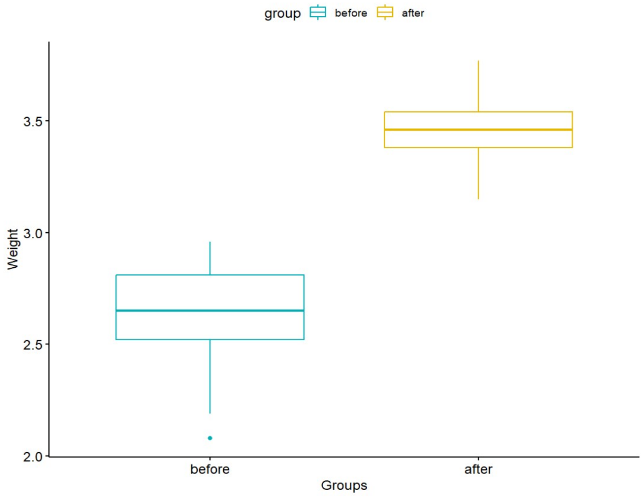


Fig. 7. Box-plot before and after.

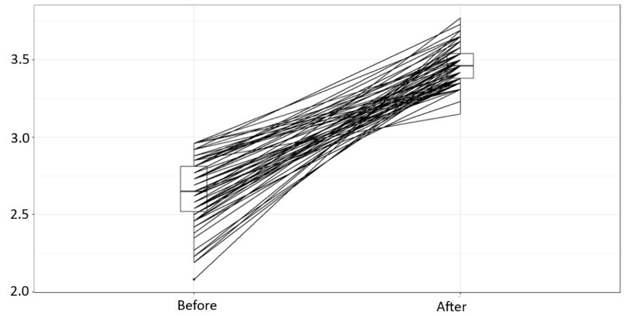


Fig. 8. Shows the paired data plot before and after.

Fig. 7 shows a Box-Plot as a summary of the sample distribution, illustrating the shape of the data distribution, central tendency, and data spread (variability). The pre-test group contains extreme data points, indicated by the lowest points, while the post-test data does not show any extreme points. Based on the resulting box plot, it is evident that there is an improvement in student creativity before and after using the CPS learning model integrated with AR teaching materials. The differences in creativity improvement for each sample are shown in more detail in Fig. 8. Fig. 8 demonstrates that all 67 students exhibited significant improvement in creativity. These results are also supported by the T-Test analysis, with the data obtained as shown in Table 3.

Table 3. Paired Samples T-Test

Test Type	Statistic Type	Statistic Value	df	*p*	Mean Difference	Effect Size Type	Effect Size Value
Post-test and Pre-test	Student's t	24.9	66.0	<0.001	0.828	Cohen's d	3.04
	Wilcoxon W	22783.04	66.0	<0.001	0.810	Rank biserial correlation	1.00

df: Degree of freedom; p: Significance; t: t-test; W: Wilcoxon; Cohen's d: Effect Size.

In the paired samples t-test table below, the *p*-value (0.001) < 0.05, therefore the alternative Hypothesis (Ha) is accepted, indicating a significant difference between the mean creativity scores before and after. To assess the effect size, the value of d = 3.04 indicates a very high or strong effect. This means that the CPS model supported by AR-integrated digital teaching materials significantly enhances students' creativity. Meanwhile, the improvements in each aspect of creativity as measured by the Creativity Questionnaire self-assessment are shown in the following figure.

In the plot results for each indicator, the highest improvement occurred in Indicator 2, which is "Digging Deeper into Ideas," followed by Indicator 4, which is "Listening to Your Inner Voice." Meanwhile, Indicators 1 and 3 showed nearly the same level of improvement in "Generating Ideas" and "Exploring Ideas." The analysis results indicate that Indicator 2 ("Digging Deeper into Ideas") showed the highest improvement compared to the other indicators. This suggests that the pre-service physics teachers were more capable of delving deeper into ideas after the intervention. The ability to explore ideas deeply is crucial, as it reflects a more mature level of exploration and understanding of a concept. Additionally, significant improvement was observed in Indicator 4 ("Listening to Your Inner Voice"). This indicator shows that students were better able to listen to and understand their intuition or inner voice during the creative thinking process. This indicates a shift toward strengthening internal processes in exploring ideas and decision-making. Meanwhile, Indicators 1 ("Generating Ideas") and 3 ("Exploring Ideas") showed relatively similar levels of improvement. Although not as high as Indicators 2 and 4, the results still show that students' ability to generate and explore ideas improved significantly. The consistent improvement in these two indicators suggests that students have a strong foundation in developing and expanding their ideas.

Overall, these findings emphasize the importance of the CPS learning model in enhancing creativity. Digging deeper into ideas and listening to one's inner voice are the most dominant aspects of this process. The combination of strengthening exploratory skills and intuitive understanding is believed to have a more significant impact on the development of innovative ideas. Students' creativity increased after implementing the CPS model supported by AR-integrated teaching materials. Creativity and collaboration are considered core competencies [54]. In CPS-based learning, students form groups and actively provide ideas during the exploration and problem-solving stages [55]. Digital teaching materials, along with the integration of Augmented Reality technology, also have a positive impact on creativity improvement, as seen in research by Wang and Li [56]. This aligns with the opinion of Akin *et al.* [57] which suggests that modifying teaching media can serve as an alternative to enhance creativity. Thus, the results of this study indicate that the CPS learning model supported by AR-integrated teaching materials can enhance students' creativity, especially in exploring ideas deeply and listening to their inner voice. Therefore, this learning model can be used as one of the alternatives to enhance students' creativity.

Creativity assessment using a self-assessment scale aims to effectively monitor students' progress and capture dynamic changes over time [40]. The limitation of the self-assessment questionnaire used in this study is that it is rarely used in research. Additionally, the reliability and validity tests for this questionnaire have so far only been conducted in Indonesia. The effect size in this study is excessively high, which is rarely found in educational research. This is likely due to bias in the self-assessment instrument for creativity. Several studies have also shown that the use of self-assessment has the potential to introduce bias [58, 59]. herefore, future research is recommended to use product-based creativity assessment instruments and ensure their validity and reliability through accurate testing.

Assessment results indicate a significant improvement in creativity, particularly in the high category. Upon review, based on Fig. 9, several differences in creativity improvements across indicators can be observed, including: 1) Diverse levels of technology literacy**.** Not all students have the same level of technology literacy. However, creativity in technology-based learning, such as Augmented Reality (AR), requires a certain level of technical understanding [60]. The use of AR requires students to master the skills of operating devices and supporting applications. Students who are less familiar with this technology tend to spend more time understanding the technology itself rather than exploring creative ideas, even though usage guidelines are provided. 2) Adaptation to AR-based collaborative learning**.** AR-based collaboration is a new approach that may not be familiar to some students. Similarly, modules or teaching materials also help in enhancing creativity [61]. However, adapting to this new method takes time, so students' creativity may not fully develop within the limited learning period. 3) Limitations of AR media features**.** The AR media used in learning has limitations in terms of features, flexibility, and visual appeal. These shortcomings can limit the potential for creative exploration by students. 4) Dominance of collaborative activities in learning**.** During collaborative learning, most of the student's time and energy are directed toward teamwork, task division, and collective problem-solving. As a result, there is less room for individual creative expression. The results of creativity are shown in Fig. 9 below.

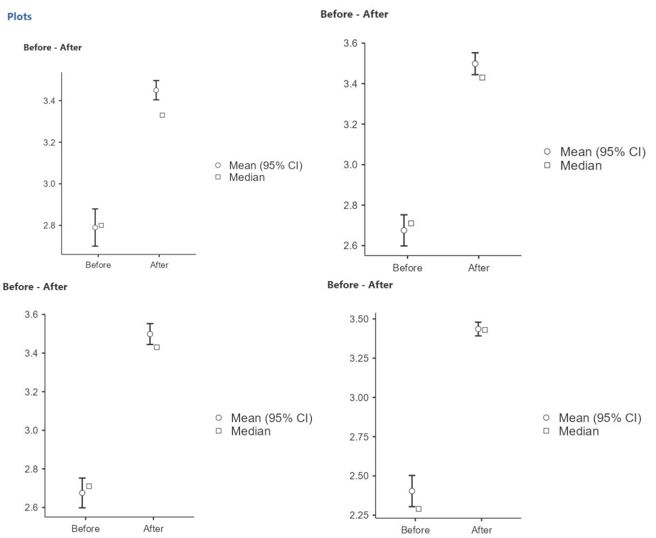
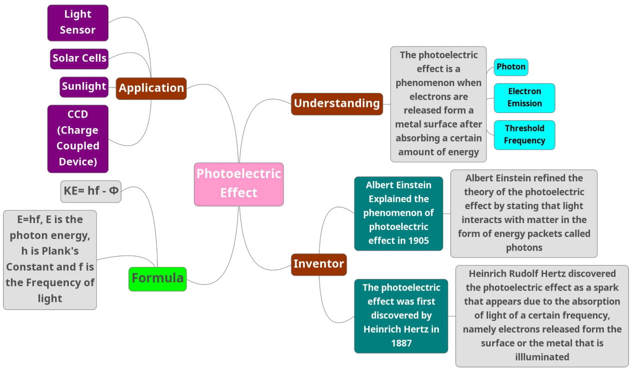


Fig. 9. Shows the box plot before and after each indicator.

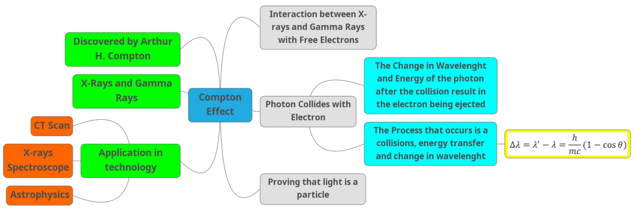
Creativity plays a crucial role in project management, as it drives the creation of new ideas and innovations, both individually and within teams. This creativity supports problem-solving and improves the overall work process [62]. In the context of this research, the CPS learning model was implemented, designed to accommodate interaction among students through idea exchange, argumentation, and analysis of various problems solved both collectively and individually. Through this approach, students' creativity is expected to be developed and enhanced.

However, a model-based learning approach alone is not sufficient. The role of learning media also plays an important part in enhancing students' creativity. Effective media can strengthen knowledge and conceptual understanding, particularly on complex topics such as modern physics and quantum physics [63]. In this case, the use of Augmented Reality (AR) media based on 3D animation visualization has been shown to have a significant impact on improving students' conceptual understanding. AR media not only helps students visualize abstract concepts but also encourages creative collaboration among them. This collaboration, in turn, contributes to the enhancement of student's creative thinking skills [35].

Students' creativity is reflected in the mind maps they create related to the topics discussed in each meeting. The creative process is related to how individuals absorb and process information and ideas until they produce creative work [64]. According to Sun *et al.* [65] the process of building a mind map helps students retain their ideas for further evaluation and elaboration in their tasks. Moreover, mind maps have been shown to improve learning achievement, and performance, as well as tendencies for creative thinking [66] and critical thinking [67]. The following are the results of students' creativity in making mind maps on the topic of the photoelectric effect and the Compton effect, which are shown in Fig. 10.



(a)



(b)

Fig. 10. The results of student creativity in making mind maps. (a) Photoelectric effect mind map; (b) Compton effect mind map.

Creativity can be defined as the effort to reconstruct a sequence of reasoning expressed in the form of creative arguments [68]. Several previous studies have shown a significant relationship between creativity and the use of mind mapping. Research Özsevgeç and Azakli [69] revealed that the use of mind maps can enhance students' creativity. Similar results were found in a study by Hidayati *et al.* [70] which indicated that students' creative thinking can be improved through the use of digital-based mind maps. Mind maps serve as a visual representation of thinking, reflecting students' ability to organize, connect, and develop ideas creatively. The process of creating a mind map provides space for students to reflect on their understanding. Creative students tend to show better abilities in evaluating their ideas, selecting the most relevant concepts, and eliminating less significant ones.

V. Conclusion

Creativity can be defined as the effort of students to create and develop their ideas. The data analysis results show a significant improvement in students' creativity before and after implementing the CPS model, supported by modern physics digital teaching materials integrated with Augmented Reality (AR). This improvement in creativity falls into the high category. Students' creativity results can be observed through the mind maps they have created. The role of engaging teaching materials and media, as well as collaborative learning, has proven to have a significant influence on students' creativity. During the learning process, students are allowed to exchange ideas, express opinions, and explore their knowledge in solving problems.

These results indicate that integrating the collaborative model, AR-based teaching materials, and mind maps can effectively develop students' creativity. Therefore, instructors and educational institutions should incorporate this learning strategy as an integral part of the curriculum to foster creativity. More intensive guidance on mind map creation methods can help students enhance their exploration and innovation abilities.

This study implies that the development of Augmented Reality (AR) technology can be effectively implemented in science learning. However, its implementation requires careful and well-planned preparation to achieve optimal results. Additionally, AR can be combined with Problem-Based Learning (PBL) and Project-Based Learning (PjBL) models to enhance learning effectiveness.

To improve the quality and interactivity of AR, audio features can be added to explain concepts. Moreover, AR applications can be tailored to students' learning styles and needs, supporting a more personalized and adaptive learning experience.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The researcher's contribution to this study is Arini Rosa Sinensis as the developer of teaching material content and collaborative problem-solving model design. Thoha Firdaus and Uli Rizki are the developers and designers of Augmented Reality. Widayanti contributed to the research data analysis process. All authors had approved the final version.

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