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Development and Implementation of Arsif Augmented Reality Learning Media to Support High School Students' Critical Thinking, Creative Thinking, and Science Process Skills in Physics Learning

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Abstrak

Penelitian ini bertujuan untuk mengembangkan serta menguji kelayakan dan efektivitas Arsif, sebuah aplikasi *Augmented Reality* (AR) berbasis Android yang dirancang untuk mendukung pembelajaran fisika pada materi sinar-sinar istimewa. Arsif dikembangkan untuk menyediakan visualisasi konsep fisika yang interaktif serta memfasilitasi peningkatan kemampuan berpikir kritis, berpikir kreatif, dan keterampilan proses sains peserta didik. Penelitian ini menggunakan metode kuasi eksperimen dengan desain *pre-test* dan *post-test nonequivalent control group*. Kelayakan media pembelajaran dinilai melalui validasi ahli yang mencakup aspek media dan aspek materi. Hasil validasi menunjukkan bahwa Arsif memperoleh skor sebesar 90% dari ahli media dan 92% dari ahli materi, yang mengindikasikan bahwa aplikasi ini sangat valid dan layak digunakan dalam pembelajaran fisika. Hasil implementasi menunjukkan adanya peningkatan pada seluruh keterampilan yang diukur. Kemampuan berpikir kritis meningkat dari 32,3% pada pretest menjadi 86,6% pada posttest, kemampuan berpikir kreatif meningkat dari 20,8% menjadi 69,9%, dan keterampilan proses sains meningkat dari 59,1% menjadi 80,1%. Temuan ini menunjukkan bahwa Arsif berpotensi mendukung peserta didik dalam memahami konsep fisika yang bersifat abstrak melalui visualisasi interaktif sekaligus meningkatkan keterampilan belajar yang esensial. Dengan demikian, media pembelajaran berbasis *Augmented Reality* dapat menjadi alternatif yang menjanjikan untuk menciptakan pengalaman pembelajaran fisika yang lebih menarik, interaktif, dan bermakna.

Kata kunci: *augmented reality*, berpikir kritis, berpikir kreatif, pembelajaran fisika

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Abstract

This study aimed to develop and examine the feasibility and effectiveness of Arsif, an Android-based Augmented Reality application designed to support physics learning on the concept of special light rays. Arsif was developed to provide interactive visualization of physics concepts and to facilitate the improvement of students' critical thinking, creative thinking, and science process skills. This study employed a quasi-experimental method with a pre-test and post-test nonequivalent control group design. The feasibility of the learning medium was assessed through expert validation involving media and material aspects. The results showed that Arsif obtained a validation score of 90% from the media expert and 92% from the material expert, indicating that the application was highly valid and feasible for use in physics learning. The implementation results showed an increase in students' scores in all measured skills. Critical thinking skills increased from 32.3% in the pretest to 86.6% in the posttest, creative thinking skills increased from 20.8% to 69.9%, and science process skills increased from 59.1% to 80.1%. These findings indicate that Arsif has the potential to support students in understanding abstract physics concepts through interactive visualization while improving essential learning skills. Therefore, augmented reality-based learning media can be considered a promising alternative for creating more engaging, interactive, and meaningful physics learning experiences.

Keywords: augmented reality, critical thinking, creative thinking, physics learning

INTRODUCTION

The rapid development of science and technology has changed the orientation of physics learning in the 21st century. Learning is no longer limited to the transmission of concepts, but is also directed toward developing students' ability to think critically, generate creative ideas, conduct scientific investigations, and use technology meaningfully. In this context, STEM-based learning provides opportunities for students to connect scientific concepts with technology, engineering design, and real-life problem solving. A STEM-based curriculum has also been reported to improve students' creative thinking, particularly in fluency, flexibility, and originality when studying physics-related contexts (Khalil et al., 2023).

Physics learning requires students to master concepts and apply them in explaining natural phenomena. However, many physics concepts are abstract, microscopic, or difficult to observe directly, causing students to experience difficulties in understanding relationships between concepts and in applying them to problem-solving situations. This condition indicates that physics learning should not only emphasize content mastery but also strengthen higher-order thinking and inquiry-based skills. Critical thinking is important because it enables students to interpret information, analyze relationships, evaluate evidence, and make reasoned decisions during scientific learning. In physics classrooms, critical thinking can be developed when students are involved in learning activities that require analysis, argumentation, design, and reflection (Putra et al., 2023).

In addition to critical thinking, creative thinking is also essential in physics learning. Creative thinking allows students to produce various ideas, propose alternative solutions, and interpret physics problems from different perspectives. The indicators of creative thinking, such as fluency, flexibility, originality, and elaboration, are closely related to students' ability to solve unfamiliar problems. Therefore, physics learning should provide space for students to explore ideas, construct explanations, and connect scientific concepts with contextual problems. Learning that integrates STEM principles can support this need because it encourages students to investigate problems, design solutions, and apply scientific knowledge creatively (Khalil et al., 2023).

Science process skills are another important aspect of physics learning. These skills include observing, measuring, classifying, predicting, interpreting data, and drawing conclusions. Science process skills help students understand science as a process of inquiry rather than merely a collection of formulas and concepts. Students who have good science process skills are expected to be able to investigate phenomena, use evidence, and communicate scientific findings appropriately. The integration of mobile augmented reality through inquiry learning has been shown to improve students' science process skills and concept mastery, indicating that technology-supported inquiry can strengthen scientific investigation activities (Setiawaty et al., 2024).

Although critical thinking, creative thinking, and science process skills are important, previous observations indicate that students still need support in making logical conclusions, generating diverse ideas, predicting scientific phenomena, and formulating conclusions based on evidence. These problems show that students require learning media that can make abstract physics concepts more concrete, interactive, and easier to explore. Technology-based learning media can become an alternative solution because it enables students to visualize phenomena, interact with learning objects, and receive more meaningful learning experiences. Mobile-based learning is particularly relevant because smartphones are increasingly accessible and can support flexible learning activities.

Augmented Reality (AR) is one of the technologies that can support physics learning by combining real environments with virtual objects. AR enables students to observe three-dimensional visualizations, manipulate digital objects, and connect abstract concepts with concrete representations. A meta-analysis of AR in science learning found that AR has the potential to support students' understanding of complex and unobservable concepts through multidimensional representations (Xu et al., 2022). In physics learning, mobile AR has been reported to help students understand abstract concepts, increase learning achievement, and create a more interesting learning environment through 3D visualization (Rahmat et al., 2023). Another study also showed that AR-based learning can improve students' critical thinking ability and learning gains in physics (Faridi et al., 2021).

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Recent studies have increasingly emphasized the use of AR in science and physics education. Research on AR in science learning has shown positive effects on students' learning retention and critical thinking in a STEAM-based environment (Alkhabra et al., 2023). A bibliometric study on AR in physics education also showed that publications in this field have increased significantly since 2017, with Indonesia becoming one of the countries contributing to AR research in physics learning (Nurjanah et al., 2024). These findings indicate that AR is a promising technology for physics education. However, most existing studies still focus on learning achievement, motivation, conceptual understanding, or single-skill improvement. Research that simultaneously examines critical thinking, creative thinking, and science process skills through AR-based physics learning is still limited.

The present study was conducted in a non-formal learning context. Non-formal learning has different characteristics from formal classroom learning because it is more flexible, learner-centered, and closely related to students' immediate learning needs. Non-formal science learning can provide authentic and hands-on experiences that support students' motivation, competence, and engagement in STEM activities (Kirchhoff et al., 2022). Therefore, implementing AR in non-formal physics learning is expected to provide an interactive learning experience that supports students in understanding abstract concepts while developing essential 21st-century skills.

Based on these considerations, this study develops and implements Arsif, an Android-based Augmented Reality learning medium for special light rays in physics. This research aims to examine the validity and effectiveness of Arsif in improving high school students' critical thinking, creative thinking, and science process skills in non-formal learning. The novelty of this study lies in the integration of AR-based physics learning with the simultaneous measurement of three essential skills: critical thinking, creative thinking, and science process skills.

METHODS

Research Design

This study employed a quantitative approach using a quasi-experimental method with a pretest-posttest nonequivalent control group design. The design was used to examine the effectiveness of an augmented reality learning medium in improving students' critical thinking, creative thinking, and science process skills. A quasi-experimental design is appropriate for educational research because learning interventions are often implemented in existing groups where full randomization is difficult to conduct. Andrade (2021) explains that quasi-experimental studies can be used when researchers aim to evaluate the effect of an intervention in a natural educational setting.

The nonequivalent control group design involved two groups: an experimental group and a control group. The experimental group received learning treatment using Arsif, an Android-based augmented reality learning medium, while the control group received non-AR learning activities. Both groups were given a pretest before the treatment and a posttest after the treatment. The pretest was administered to identify students' initial abilities, while the posttest was used to measure changes after the learning process. This design allows researchers to compare students' abilities before and after the intervention and to evaluate the difference in improvement between the experimental and control groups. According to Bulus (2021), a pre-test-post-test control group design is useful for estimating intervention effects because it enables researchers to observe changes in participants' performance after treatment.

Table 1. Pre-Test-Post-Test Nonequivalent Control Group Design

Group	Pretest	Treatment	Posttest
Experimental group	Y1	X	Y2
Control group	Y1	C	Y2

Note: Y1 = pretest; Y2 = posttest; X = learning using Arsif augmented reality medium; C = non-AR learning.

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Research Context and Student Characteristics

This research was conducted in a non-formal physics learning context. Non-formal learning has flexible characteristics and provides opportunities for students to participate in learning activities based on their interests, needs, and learning goals. In this context, students are encouraged to be more active, independent, and responsible for their learning process. Therefore, learning media used in non-formal education should be able to attract students' attention, support independent exploration, and help them understand concepts through meaningful learning experiences.

Student characteristics were considered in the development and implementation of the learning medium. These characteristics included learning interest, motivation, curiosity, learning readiness, and initial thinking ability. Students in non-formal learning generally require learning activities that are flexible, contextual, and directly connected to the concepts being studied. Therefore, the use of augmented reality was considered relevant because it provides interactive visualization and allows students to observe abstract physics concepts in a more concrete form. Wibowo (2023) states that augmented reality can support physics learning by facilitating students' interaction with visual objects and strengthening 21st-century skills.

Learning Medium and Treatment

The learning medium used in this study was Arsif, which stands for Augmented Reality Sinar Istimewa Physics. Arsif was developed as an Android-based learning medium to support students in understanding physics concepts through augmented reality visualization. The application presents learning materials, visual objects, and learning activities designed to help students explore the concept of special light rays.

In the experimental group, Arsif was used as the main learning medium. Students interacted with augmented reality objects, observed the visualization of light rays, and completed learning tasks related to the indicators of critical thinking, creative thinking, and science process skills. Through this activity, students were expected to analyze visual information, propose explanations, develop ideas, predict phenomena, and draw conclusions based on the observed learning objects.

The control group learned the same topic through non-AR learning activities. The learning objectives and assessment indicators in both groups were made similar so that the difference in students' learning outcomes could be associated with the use of augmented reality media. This comparison was conducted to determine whether the use of Arsif could provide a better improvement in students' critical thinking, creative thinking, and science process skills compared to non-AR learning.

Research Instruments

The instruments used in this study consisted of validation sheets and essay tests. The validation sheets were used to assess the feasibility of the Arsif learning medium before implementation. The validation process involved media and material aspects, including content suitability, visual display, language clarity, technical performance, interactivity, and relevance to learning objectives.

The essay tests were used to measure students' critical thinking, creative thinking, and science process skills. Essay tests were selected because they allow students to explain their reasoning, describe problem-solving processes, and present arguments more deeply. Critical thinking was assessed through indicators such as interpretation, analysis, evaluation, explanation, and conclusion-making. Lina and Desnita (2022) emphasize that critical thinking instruments in physics learning should measure students' ability to analyze information and construct logical explanations based on physics concepts.

Creative thinking was measured using indicators of fluency, flexibility, originality, and elaboration. Fluency refers to students' ability to produce several relevant ideas, while flexibility refers to their ability to provide various perspectives or solution strategies. Originality reflects the uniqueness of students' answers, and elaboration refers to their ability to explain ideas in detail. Utama et al. (2021) state that creative thinking instruments in physics should be constructed based on clear indicators so that students' creative responses can be measured systematically. Tanjung and Nasution (2022) also explain that the indicators of fluency, flexibility, originality, and elaboration are commonly used to assess creative thinking in physics learning.

Science process skills were measured through indicators such as observing, measuring, predicting, interpreting data, and drawing conclusions. These indicators were used because science process skills are closely related to students' ability to conduct scientific reasoning and investigate phenomena. Fadilla et al. (2023) explain that science process skills instruments in physics should be developed by considering content validity, item quality, and suitability with students' cognitive ability. Therefore, the test items in this study were designed to assess not only students' final answers but also their scientific reasoning process.

Instrument Validation

The Arsif learning medium and research instruments were validated before being used in the learning process. The validation was conducted to ensure that the learning medium, test items, and scoring rubrics were appropriate for measuring the intended skills. The validation process focused on four main aspects: content, construction, language, and media quality.

Content validation examined the suitability of the materials with physics concepts and learning objectives. Construction validation examined the clarity of item structure, assessment indicators, and scoring rubrics. Language validation examined the readability, clarity, and accuracy of the statements used in the instruments. Media validation examined the visual quality, navigation, usability, interactivity, and technical performance of the Arsif application. The validation results were analyzed using a percentage formula:

$$\text{Validity percentage} = (\text{obtained score} / \text{maximum score}) \times 100\%$$

The validation results were then interpreted into feasibility categories. Learning media and instruments categorized as valid or very valid were considered feasible to be implemented after revision based on expert suggestions. This validation process was important to ensure that the instruments measured the intended variables consistently and that the learning medium was suitable for use in physics learning.

Research Procedure

The research procedure consisted of preparation, validation, implementation, and evaluation stages. In the preparation stage, the researchers developed the Arsif learning medium, prepared learning materials, designed test instruments, and constructed scoring rubrics. The instruments were designed based on the indicators of critical thinking, creative thinking, and science process skills.

In the validation stage, the learning medium and instruments were reviewed by experts. Suggestions from validators were used to improve the content, language, display, and technical aspects of the learning medium and instruments. After revision, the instruments and learning medium were implemented in the learning process. In the implementation stage, both the experimental and control groups were given a pretest to determine their initial abilities.

After that, the experimental group learned using Arsif, while the control group learned through non-AR learning activities. During the learning process, students were guided to understand the concept of special light rays and to complete tasks related to the three measured skills. In the evaluation stage, both groups were given a posttest. The posttest results were compared with the pretest results to determine the improvement in students' critical thinking, creative thinking, and science process skills. The data obtained from the pretest and posttest were then analyzed quantitatively.

Data Analysis

The data were analyzed using descriptive and inferential statistics. Descriptive analysis was used to describe students' pretest and posttest scores, including mean score, percentage, standard deviation, minimum score, and maximum score. This analysis provided an overview of students' initial and final abilities in each measured variable.

Before conducting hypothesis testing, prerequisite tests were carried out. The normality test was used to determine whether the data were normally distributed, while the homogeneity test was used to determine whether the variance between groups was homogeneous. If the data met the assumptions of parametric statistics, a paired-sample t-test was used to analyze the difference between pretest and posttest scores within each group, while an independent-sample t-test was used to compare the improvement between the experimental and control groups. If the data did not meet parametric assumptions, non-parametric tests were used as alternatives.

The improvement in students' skills was also analyzed using the normalized gain score. The N-gain score was used to determine the level of improvement from pretest to posttest. The formula used was:

N-gain = (posttest score − pretest score) / (maximum score − pretest score)

The N-gain results were categorized into low, medium, and high improvement levels. In addition, effect size analysis was used to determine the strength of the treatment effect. Through this analysis, the effectiveness of Arsif as an augmented reality learning medium could be evaluated more comprehensively, not only based on score improvement but also based on the magnitude of its effect on students' critical thinking, creative thinking, and science process skills.

RESULT AND DISCUSSION

Results

The results of this study consist of two main findings: the validation results of the Arsif learning medium and the assessment results of students' critical thinking, creative thinking, and science process skills. The validation stage was conducted to determine the feasibility of the augmented reality learning medium before it was implemented in the learning process. The assessment stage was conducted by comparing students' pretest and posttest scores after the implementation of Arsif.

Validation Results of Arsif Learning Medium

Arsif, which stands for Augmented Reality Sinar Istimewa Physics, was developed as an Android-based learning medium to support students in understanding the concept of special light rays. Before being implemented in the learning process, the medium was validated by media and material experts. The validation results are presented in Table 2.

Table 2. Validation results of Arsif learning medium

No	Expert Validation	Validation results
1.	Media Expert	90%
2.	Materials Expert	92%

Table 2 shows that the Arsif learning medium obtained a validation score of 90% from the media expert and 92% from the material expert. These results indicate that Arsif was categorized as highly valid and feasible to be used in physics learning. The high score from the media expert shows that the application had appropriate visual quality, navigation, interactivity, and technical performance. Meanwhile, the high score from the material expert indicates that the content presented in Arsif was suitable for the learning objectives and relevant to the physics concept being studied.

Students' Pretest and Posttest Results

The effectiveness of Arsif was examined by comparing students' pretest and posttest scores on three measured skills: critical thinking, creative thinking, and science process skills. The results are presented in Table 3.

Table 3. Students Pretest And Posttest Results

No	Skill	Pretest	Posttest	Score increase	N-gain	Category
1	Critical thinking	32.3%	86.6%	54.3%	0.80	High
2	Creative thinking	20.8%	69.9%	49.1%	0.62	Medium
3	Science process skills	59.1%	80.1%	21.0%	0.51	Medium

Table 3 shows that all measured skills increased after the implementation of Arsif. Critical thinking skills increased from 32.3% in the pretest to 86.6% in the posttest, with an increase of 54.3 percentage points. The N-gain score for critical thinking was 0.80, which is categorized as high. This result indicates that the use of Arsif strongly supported students in analyzing information, making decisions, and drawing conclusions based on physics concepts.

Creative thinking skills also increased from 20.8% in the pretest to 69.9% in the posttest. The increase reached 49.1 percentage points, with an N-gain score of 0.62, which is categorized as medium. This improvement indicates that students became more capable of generating ideas, providing alternative answers, and developing explanations after learning with the augmented reality medium.

Science process skills increased from 59.1% in the pretest to 80.1% in the posttest. The increase reached 21.0 percentage points, with an N-gain score of 0.51, which is categorized as medium. This result shows that Arsif helped students improve their ability to observe, predict, interpret, and draw conclusions related to the concept of special light rays.

The comparison of pretest and posttest scores is presented in Figure 1:

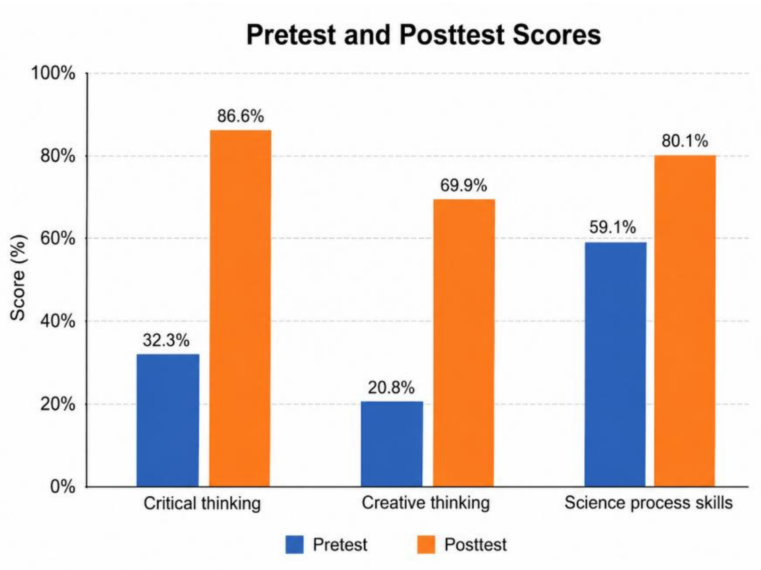

Figure 1. Pretest And Posttest Scores Of Students Critical Thinking, Creative Thinking, And Science Process Skills

Based on Figure 1, the posttest scores of all measured skills were higher than the pretest scores. The highest increase was found in critical thinking skills, followed by creative thinking skills and science process skills. These findings indicate that the augmented reality learning medium provided a positive contribution to students' learning development. Through interactive visualization, students were able to observe physics concepts more clearly, connect visual information with conceptual understanding, and construct explanations based on the learning activities.

Overall, the results show that Arsif was valid and effective as an augmented reality learning medium. The validation scores from experts indicate that the application was feasible to use, while the pretest and posttest results show that the application improved students' critical thinking, creative thinking, and science process skills. Therefore, Arsif can be considered a potential learning medium to support physics learning, especially for topics that require visualization and conceptual understanding.

Discussion

The validation results show that Arsif is feasible to be implemented as an augmented reality learning medium in physics learning. The application obtained a validation score of 92% from the material expert and 90% from the media expert. These results indicate that the content, visual display, media design, and technical aspects of Arsif were considered suitable for supporting

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the learning objectives. This finding is in line with Haryadi and Pujiastuti (2022), who found that AR-based physics learning media can be categorized as feasible when it receives positive validation from media and material experts. Similarly, Yusa et al. (2023) reported that AR-based learning media can be implemented in science learning after being declared valid by experts and receiving positive student responses.

The high validation score from the material expert indicates that the physics content presented in Arsif was relevant to the learning objectives and appropriate to the concept of special light rays. In physics learning, content validity is important because students need accurate scientific representations to avoid misconceptions. The high validation score from the media expert also indicates that Arsif had appropriate visual quality, navigation, and interactivity. Khoiriyah et al. (2025) stated that AR-based physics media can support students' concept understanding when the media is designed with feasible content, good visualization, and positive learning responses. Therefore, the validation results in this study suggest that Arsif has the potential to be used as a supportive medium for visualizing abstract physics concepts.

The implementation of Arsif also contributed to the improvement of students' critical thinking skills. The pretest score of critical thinking was 32.3%, while the posttest score increased to 86.6%. This increase indicates that students showed better ability to analyze information, connect concepts, and draw conclusions after learning with AR media. The improvement can be explained by the characteristics of AR, which allows students to observe visual representations of physics concepts and relate them to problem-solving activities. Demircioglu et al. (2023) found that AR-based argumentation activities can support students' critical thinking and argumentation in science learning. In the context of this study, Arsif provided students with visual and interactive learning experiences that encouraged them to process information more deeply before making conclusions.

This result is also consistent with Dewi and Kuswanto (2023), who reported that an augmented reality-assisted physics e-module was effective in improving students' critical thinking ability. AR media can help students understand physics concepts because it presents objects and phenomena that are difficult to observe directly through more concrete visualizations. Marsila et al. (2026) also found that AR-based physics learning using Assemblr Edu improved students' critical thinking skills in static fluid material. These findings strengthen the interpretation that AR can be an effective medium for helping students move from passive reception of information to active analysis and evaluation of physics phenomena (Fandayati & Kurniawan, 2022; Fandayati et al., 2024).

Creative thinking skills also improved after students learned using Arsif. The pretest score of creative thinking was 20.8%, while the posttest score increased to 69.9%. This improvement shows that students have become more capable of generating ideas, providing alternative explanations, and developing more varied responses. In creative thinking assessment, fluency, flexibility, originality, and elaboration are important indicators because they show how students produce and develop ideas (Kurniawan, 2024). Apriani et al. (2021) found that students who learned using AR-assisted physics worksheets had better creative thinking ability than students who did not use AR, especially in fluency, originality, and elaboration. The improvement in this study indicates that the interactive visualization in Arsif helped students explore physics concepts in a more flexible and imaginative way.

The increase in creative thinking skills may also be related to the opportunity for students to interact with learning objects rather than only reading or listening to explanations. Through AR visualization, students can observe the direction of light rays, identify relationships among concepts, and construct explanations based on what they see. This learning condition supports the development of alternative ideas because students are not limited to static images or verbal descriptions. Chang et al. (2022) showed through a meta-analysis that AR has a positive impact on educational outcomes, including knowledge, skills, and performance. Therefore, the improvement of creative thinking in this study can be interpreted as part of the broader contribution of AR to students' active and constructive learning processes.

Science process skills also increased from 59.1% in the pretest to 80.1% in the posttest. This result indicates that Arsif helped students improve their ability to observe, predict, interpret, and draw conclusions in physics learning. Science process skills are important because students need to understand not only the final concept but also the process of obtaining scientific knowledge. Liao et al. (2025) found that an AR lens imaging learning system improved students' science achievement, motivation, and inquiry skills in physics inquiry activities. This finding is relevant to the present study because Arsif also used visualization to support students in observing and interpreting physics phenomena.

The improvement in science process skills can be understood from the role of AR in providing concrete representations of abstract concepts. When students interact with AR objects, they can observe visual phenomena more directly, make predictions based on the objects displayed, and draw conclusions from the learning activities. Anam et al. (2025) emphasized that the integration of real and virtual experimentation can support students' conceptual knowledge and science process skills. Although Arsif does not fully replace real laboratory activities, it provides virtual visualization that can help students understand scientific processes when direct observation is limited.

The findings of this study indicate that AR media can support the development of critical thinking, creative thinking, and science process skills simultaneously. This is important because physics learning requires students to understand concepts, analyze problems, generate ideas, and use scientific reasoning. AR does not only function as a visual aid, but also as a learning environment that encourages students to observe, question, interpret, and explain phenomena. This is consistent with the broader trend in educational technology, where AR is increasingly used to create more interactive and meaningful learning experiences. Chang et al. (2022) explained that AR learning has been widely shown to influence students' learning outcomes across various educational settings.

In the context of non-formal learning, the use of Arsif is particularly relevant because students need flexible and engaging learning media. Non-formal learning requires learning activities that can maintain motivation, encourage independent exploration, and help students connect learning materials with real situations. Yusa et al. (2023) reported that AR-based mobile applications can be used anytime and anywhere and can increase students' motivation and learning outcomes. This supports the findings of the present study that Arsif can become a potential medium for non-formal physics learning because it provides interactive access to learning materials through Android devices.

Overall, the results show that Arsif is valid and has a positive contribution to students' learning development. The highest improvement was found in critical thinking skills, followed by creative thinking and science process skills. These findings indicate that the use of AR visualization in physics learning can help students understand abstract concepts, construct explanations, and develop higher-order thinking skills. However, the interpretation of the results should still be made carefully because the data presented in this study are based on pretest and posttest percentages. Further statistical analysis, such as normality test, homogeneity test, t-test, N-gain, and effect size, is needed to strengthen the evidence of effectiveness. Therefore, Arsif can be considered a promising augmented reality learning medium, but its effectiveness should be further confirmed through more comprehensive statistical testing.

CONCLUSION

This study developed and implemented Arsif, an Android-based Augmented Reality learning medium designed to support physics learning on the concept of special light rays. The validation results showed that Arsif obtained a score of 90% from the media expert and 92% from the material expert. These results indicate that the application was categorized as highly valid and feasible to be used as a learning medium.

The implementation of Arsif showed positive results in improving students' critical thinking, creative thinking, and science process skills. Students' critical thinking skills increased from 32.3% in the pretest to 86.6% in the posttest. Creative thinking skills increased from 20.8% to 69.9%, while science process skills increased from 59.1% to 80.1%. These findings indicate that the use of augmented reality learning media can help students understand abstract physics concepts through interactive visualization and support the development of essential learning skills.

The improvement in critical thinking skills indicates that students became more capable of analyzing information, making decisions, and drawing conclusions based on physics concepts.

The improvement in creative thinking skills shows that students were encouraged to generate ideas, provide alternative explanations, and elaborate their understanding more clearly. Meanwhile, the improvement in science process skills suggests that students were better able to observe, predict, interpret, and conclude scientific phenomena after learning with Arsif.

Overall, Arsif can be considered a potential learning medium for supporting physics learning in a non-formal education context. Its interactive and visual features provide students with opportunities to explore physics concepts more actively and meaningfully. However, the findings of this study should be interpreted carefully because the effectiveness of the application was analyzed based on pretest and posttest score improvement. Further studies are recommended to involve broader participants, apply inferential statistical analysis, and examine the use of Arsif in different physics topics to obtain stronger evidence regarding its effectiveness.

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