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# Designing and Assessing Problem-Solving-Based Augmented Reality for Elementary Earth Science Education

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***A B S T R A K.*** *Permasalahan rendahnya hasil belajar siswa pada materi lapisan dan struktur Bumi menuntut inovasi media pembelajaran yang mampu memadukan teknologi dengan pendekatan pedagogis yang tepat. Penelitian ini bertujuan untuk mengembangkan media interaktif* augmented reality *berbasis* problem-solving *yang valid, praktis, dan efektif digunakan untuk meningkatkan hasil belajar siswa. Penelitian ini merupakan penelitian pengembangan dengan mengadopsi model ADDIE. Subjek penelitian meliputi dua ahli materi, dua ahli media, tiga siswa kelas V untuk uji coba perorangan, sembilan siswa kelas V untuk uji coba kelompok kecil, satu guru kelas V untuk uji kepraktisan guru, serta sembilan belas siswa kelas V untuk uji efektivitas. Data diperoleh melalui lembar validasi, angket kepraktisan, serta tes hasil belajar, kemudian dianalisis dengan teknik deskriptif kuantitatif dan uji statistik inferensial. Hasil penelitian menunjukkan bahwa media AR berbasis* problem-solving *memperoleh indeks validitas materi sebesar 0,97 dan media sebesar 0,98 dengan kualifikasi sangat valid. Kepraktisan memperoleh skor 91,67% pada uji perorangan, 92,22% pada uji kelompok kecil, dan 98,75% pada guru. Efektivitas ditunjukkan melalui uji hipotesis dengan nilai signifikansi p = 0,001 < 0,05, yang berarti terdapat perbedaan signifikan hasil belajar sebelum dan sesudah menggunakan media. Simpulan penelitian menegaskan bahwa media interaktif AR berbasis* problem-solving *valid, praktis, dan efektif.*

**A B S T R A C T.** The problem of low student learning outcomes in the material of the layers and structure of the Earth requires innovation in learning media that can combine technology with an appropriate pedagogical approach. This study aims to develop interactive augmented reality media based on valid, practical, and effective problem-solving to improve student learning outcomes. This research is a development research by adopting the ADDIE model. The research subjects included two material experts, two media experts, three fifth-grade students for individual trials, nine fifth-grade students for small-group trials, one fifth-grade teacher for teacher practicality tests, and nineteen fifth-grade students for effectiveness tests. Data were obtained through validation sheets, practicality questionnaires, and learning outcome tests, then analyzed using quantitative descriptive techniques and inferential statistical tests. The results showed that problem-solving-based AR media obtained a material validity index of 0.97 and a media validity index of 0.98 with a very valid qualification. Practicality scored 91.67% in the individual test, 92.22% in the small-group test, and 98.75% in the teacher test. Effectiveness was demonstrated through a hypothesis test with a significance value of $p = 0.001 < 0.05$, indicating a significant difference in learning outcomes before and after using the media. The study's conclusion confirms that interactive AR media based on problem-solving is valid, practical, and effective.

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## 1. INTRODUCTION

Education is a systematic process to develop individual potential through strengthening cognitive, affective, and psychomotor values (Artawan et al., 2023; Pratama et al., 2023). Educational values are expected to be inherited and internalized in every individual personality trait to acquire knowledge, skills, values, and behavioral systems to support the success of life and improve self-existence (Hasan et al., 2021; Hidayat & Abdillah, 2019). Education as a lifelong process cannot be separated from the influence of technological developments that require education to continue to

innovate (Putri, 2023; Yusuf, 2023). Educational innovation is no longer an alternative but has become necessary (Ambarwati et al., 2022; Najib & Maunah, 2022; Romadi et al., 2023). Educational innovation is an effort to create positive changes in the education system by adopting the latest approaches, ideas, and technology, including using media in learning (Iswahyudi et al., 2023; Rahmawati & Nurachadija, 2023). Learning media is an integral part of the learning process, streamlining the learning process following student development. Jean Piaget stated that the cognitive development of elementary school students aged 7-12 is at the concrete operational stage (Imanulhaq & Ichsan, 2022; Nugraha et al., 2021). Based on this situation, using learning media in elementary school students is essential because they need concrete objects to understand new concepts (Fransiska et al., 2024; Imanulhaq & Ichsan, 2022). The reality in the school shows that the learning process has not fully utilized learning media optimally, especially in learning the IPAS content material. IPAS is one of the elementary school subjects that discusses many concrete objects and natural events with abstract concepts (Fitri et al., 2024; Pitaloka & Shokib, 2024). Without learning media, student mastery of IPAS material will be less than optimal, affecting student learning outcomes. This statement is supported by the results of interviews and document analysis of student learning outcomes carried out at SD Negeri 8 Mas.

Analysis of learning outcome documents shows that 59% of students have not completed the IPAS KKTP that has been determined. The teacher explained that this happened because of the lack of availability of interactive learning media at school. The IPAS learning process more often utilizes printed books with limited material coverage and less interaction, so teachers have difficulty providing students with teaching materials, primarily abstract material. This difficulty is based on the limited classroom space to present concretely related abstract concepts when only utilizing printed books from schools. Teachers have overcome these difficulties several times by using learning videos, but it will become boring if students continue to be presented with learning videos. Teachers realize that students are more interested in digital media, but teachers have limited technological knowledge to provide digital media in the learning process, other than learning videos. In line with the teacher's statement, the results of the questionnaire to students show that all students agree that learning will become more interesting if it involves digital media in learning, and tedious if it continues to use the same media. The students' interest in digital activities should be utilized to improve their learning experience using technology-based interactive learning media (Ifriza et al., 2022; Sabila & Maghfuroh, 2025).

Augmented reality is one of the technology-based interactive learning media that has become a trend in education in this era (Muskhir et al., 2024; Rahmi et al., 2023). Augmented reality (AR), first introduced by Caudell and Mizell, is a technology that overlays digital information onto the real-world environment, enhancing the user's perception by integrating relevant data into their field of view (Caudell & Mizell, 1992). This innovative technology seamlessly merges computer-generated 3D or 2D objects with the physical surroundings, creating an immersive and interactive experience that makes digital elements appear to coexist with the real world (Ifriza et al., 2022; Ismayani, 2020). The application of AR in education has demonstrated significant potential in enhancing students' comprehension and engagement. By integrating real-time 3D visualizations, text, video, audio, and images, AR-based learning provides a rich, multimodal experience that caters to various learning styles and accelerates students' understanding of complex concepts (Refdinal, 2022; Wibowo et al., 2022). This dynamic interaction fosters deeper cognitive processing, making abstract subjects more concrete and easier to grasp. Research has shown that AR interactive media are crucial in improving students' ability to comprehend abstract topics by providing tangible, hands-on learning experiences (Resti et al., 2024; Sungkono et al., 2022). In the context of IPAS learning, teachers have reported that certain topics remain particularly challenging for students due to their abstract nature. One such topic is the Earth's layers and structure, which involves conceptualizing geological formations that are not directly observable in daily life. Interviews with teachers indicate that students often struggle to visualize and internalize these abstract concepts, leading to difficulties in comprehension. Given these challenges, AR is a highly suitable technology for developing interactive learning media that can effectively illustrate the Earth's layers and structure. Previous research has affirmed that AR is an ideal technology for development and an interactive learning medium to discuss the material of the Earth's layers and structure (Deli, 2020; Isty et al., 2021).

Using AR in learning, besides visualizing abstract concepts, can also improve students' ability to understand and solve real-world problems (Alzahrani, 2020). Students in the current era need problem-solving skills to adapt to the development of a global society. Being skilled in solving problems means that students can overcome existing problems by thinking critically (Mardhiyah et al., 2021; Wedyawati et al., 2020). Forming problem-solving skills for students is not enough to use the lecture method in learning. One of the learning methods that can shape students' problem-solving skills is the problem-solving method. The problem-solving method is a learning method that involves the ability to seek information, analyze situations, and identify problems to produce alternatives to make decisions to achieve goals (Fitrisyahni & Ningsih, 2023; Wedyawati et al., 2020). By engaging in this process, students develop cognitive flexibility and adaptability and enhance their capacity to apply their knowledge to real-world situations. Research has shown that implementing problem-solving methods in learning significantly improves student engagement, comprehension, and overall academic achievement (Akbar, 2024; Fitrisyahni & Ningsih, 2023). Integrating AR technology with the problem-solving method offers a highly interactive and immersive learning experience that enhances students' cognitive abilities. When combined with problem-solving strategies, AR can actively involve students in hands-on activities, encouraging them to think critically, analyze challenges from multiple perspectives, and develop effective solutions. This synergy strengthens students' problem-solving skills and positively impacts learning outcomes (Hui et al., 2024).

Numerous studies have explored the implementation of AR in interactive learning media. For instance, research has demonstrated that AR media applied to Earth layer materials meet feasibility qualifications for supporting the learning process (Deli, 2020; Isty et al., 2021). Furthermore, AR-based learning media are valid for instructional use and effectively enhance students' learning outcomes (Pramesila, 2022; Umri et al., 2023). Building upon these findings, this study aims to develop problem-solving-based AR interactive learning media focused on the layers and structure of the Earth for fifth-grade elementary school students to enhance their learning outcomes. This research is particularly important due to the growing demand for innovative learning media in schools. Moreover, most previous AR development research has emphasized technological aspects without integrating appropriate pedagogical approaches. The novelty of this research lies in the incorporation of problem-solving methods into AR interactive media, which has not been extensively explored in prior research. This research aims to develop problem-solving-based augmented reality interactive media, describe the validity of problem-solving-based AR interactive media, the practicality of problem-solving-based AR interactive media, and the effectiveness of problem-solving-based AR interactive media in enhancing students' learning outcomes.

## 2. METHOD

This research is part of Research and Development, which adopted the ADDIE development model. The ADDIE model consists of five stages: analysis, design, development, implementation, and evaluation. The ADDIE model has advantages in all its stages, which always go through the evaluation stage, thus reducing errors and shortcomings from the beginning of development (Sitanggang et al., 2023). The ADDIE model is one of the models for designing and evaluating learning experiences and learning content systematically and programmatically (Spatioti et al., 2022). In the ADDIE model, each stage has results that support the next stage, so it is considered very suitable for developing learning media. Based on this statement, the ADDIE model was chosen in this development research because the steps are ideal for developing learning media, especially AR interactive media. The trial subjects of this research consisted of two material experts, two media experts, three fifth-grade students for individual trials, nine fifth-grade students for small group trials, one fifth-grade teacher for teacher practicality trials, and nineteen fifth-grade students for testing effectiveness. The data collection techniques used in this research were questionnaires and tests. The instruments used were questionnaires and multiple-choice tests. The grids of data collection instruments used in this research are presented in Table 1, Table 2, Table 3, Table 4, and Table 5.

**Table 1.** Material Expert Grid

| No. | Aspects | | Indicator | Item Number |
|---|---|---|---|---|
| 1 | Learning | a. | The material is suitable for the specified learning outcomes. | 1 |
| | | b. | Suitability of material with learning objectives | 2 |
| | | c. | Correctness of difficulty level with the user | 3 |
| 2 | Content quality | a. | Correctness of material structure | 4 |
| | | b. | Accuracy of material content | 5 |
| | | c. | Consistency of material with the subject matter | 6 |
| | | d. | Clarity of material | 7 |
| 3 | Linguistics | a. | Grammatical correctness | 8 |
| | | b. | Correct spelling and punctuation | 9 |
| | | c. | Vocabulary correctness | 10 |

(Source: Modified from Surjono, 2017)

**Table 2.** Media Expert Grid

| No. | Aspects | | Indicator | Item Number |
|---|---|---|---|---|
| 1 | Learning | a. | Clarity of learning objectives | 1 |
| | | b. | Clarity of instructions for use | 2 |
| | | c. | Ease of media integration in learning | 3 |
| | | d. | Building learning motivation | 4 |
| | | e. | Building interactivity | 5 |
| 2 | View | a. | Appropriateness of AR media text type and size | 6, 7 |
| | | b. | Quality of 3D elements in AR media | 8 |
| | | c. | Appropriateness of using AR media supporting images | 9 |
| | | d. | Color harmony in AR media | 10 |
| | | e. | Appropriateness of media element layout | 11 |
| | | f. | Audio quality in AR media | 12 |
| | | g. | Video quality in AR media | 13 |
| | | h. | Ease of understanding the media user interface | 14 |
| | | i. | AR marker image quality | 15 |

| No. | Aspects | | Indicator | Item Number |
|---|---|---|---|---|
| 3 | Programming | a. | The accuracy of the hyperlink between the AR media scene | 16 |
| | | b. | Media does not overload smartphone devices | 17 |
| | | c. | Media response to marker images | 18 |
| | | d. | Media containing exercises | 19 |
| | | e. | Ease of access to AR media | 20 |

(Source: Modified from Surjono, 2017)

**Table 3.** Individual and Small Group Trial Grids

| No. | Aspects | | Indicator | Item Number |
|---|---|---|---|---|
| 1 | Media | a. | The attractiveness of the AR media display | 1 |
| | | b. | Ease of use of AR media | 2 |
| | | c. | Media response to marker images | 3 |
| 2 | Material | a. | Ease of understanding the material | 4 |
| | | b. | Suitability of the problem with the material | 5 |
| | | c. | Appropriateness of material depth | 6 |
| | | d. | Accuracy of language used | 7 |
| 3 | Media Elements | a. | Readability of text | 8 |
| | | b. | Quality of 3D objects in AR | 9 |
| | | c. | AR supporting image quality | 10 |
| | | d. | Audio quality of AR media | 11 |
| | | e. | AR media video quality | 12 |
| | | f. | Marker image quality | 13 |
| 4 | Evaluation | a. | The questions displayed are following the material | 14 |
| | | b. | Quiz attractiveness | 15 |

(Source: Modified from Surjono, 2017)

**Table 4.** Teacher Practicality Grid

| No. | Aspects | | Indicator | Item Number |
|---|---|---|---|---|
| 1 | Learning | a. | Clarity of learning objectives | 1 |
| | | b. | Clarity of instructions for use | 2 |
| | | c. | Ease of media integration in learning | 3 |
| | | d. | Media's ability to overcome space limitations | 4 |
| | | e. | Building interactivity | 5 |
| 2 | Media | a. | The attractiveness of the AR media display | 6 |
| | | b. | Ease of use of AR media | 7 |
| | | c. | Media response to marker images | 8 |
| 3 | Material | a. | Ease of understanding the material | 9 |
| | | b. | Suitability of the problem with the material | 10 |
| | | c. | Appropriateness of material depth | 11 |
| | | d. | Accuracy of language used | 12 |
| 4 | Media Elements | a. | Readability of text | 13 |
| | | b. | Quality of 3D objects in AR | 14 |
| | | c. | AR supporting image quality | 15 |
| | | d. | Audio quality of AR media | 16 |
| | | e. | AR media video quality | 17 |
| | | f. | Marker image quality | 18 |
| 5 | Evaluation | a. | The questions displayed are following the material | 19 |
| | | b. | Quiz attractiveness | 20 |

(Source: Modified from Surjono, 2017)

**Table 5.** Multiple-Choice Test Grid

| No. | Learning Objectives | Indicator | Cognitive Level | Item Number |
|---|---|---|---|---|
| 1 | By applying AR media, students can understand the layers and structure of the Earth appropriately. | Presented with a statement, students can understand the layers and structure of the Earth in question. | C2 | 1, 2, 3, 4, 5, 12, 13, 15, 22, 24 |
| 2 | By applying AR media, students can analyze the layers and structure of the Earth appropriately. | Presented with a picture or statement, students can analyze the layers and structure of the Earth. | C4 | 7, 8, 9, 10, 14, 16, 17, 19, 23, |

| No. | Learning Objectives | Indicator | Cognitive Level | Item Number |
|---|---|---|---|---|
| 3 | By applying AR media, students can solve the problem of Earth's layers and structure appropriately. | Presented with problems through pictures or statements, students solve problems related to the layers and structure of the Earth. | C4 | 25, 26, 27, 28, 29<br>6, 11, 18, 20, 21, 30 |

The questionnaire instrument in this research was first tested for validity before use. The validity of the questionnaire instrument content was tested through expert judgment (Retnawati, 2016). The instrument's content validity criteria in this research were determined using Gregory's expert agreement. The experts' assessment results will be analyzed using a 2x2 cross-tabulation. Multiple-choice test questions in this research were tested for feasibility before use. The test determined the validity, reliability, differentiation, and difficulty level of multiple-choice questions. Data analysis techniques used to process research data are quantitative descriptive analysis and inferential statistical analysis. Quantitative descriptive analysis was used to analyze validity data using Aiken's formula and practicality data using the average percentage formula. Inferential statistical analysis was used to analyze student pre-test and post-test data to conclude media effectiveness through the paired sample t-test.

## 3. RESULT AND DISCUSSION

### Result

This research develops problem-solving-based AR interactive media products focused on the material and layers of the Earth for fifth-grade elementary students. This media was designed to enhance student learning outcomes. This research was conducted at SD Negeri 8 Mas. This research was carried out based on the five stages of the ADDIE model: analysis, design, development, implementation, and evaluation. In the analysis stage, a product needs analysis is carried out, analyzing the needs in learning, student characteristics, and subject matter. The analysis stage becomes the optimal function to determine the need for problem-solving-based AR interactive media development. The design stage produces learning media material and the elements that build the AR interactive media. The design stage also produces flowcharts and storyboards that guide the flow of AR interactive media preparation. The material used in developing this AR interactive media is the material of the layers and structure of the Earth in fifth-grade elementary school, which discusses the atmosphere, lithosphere, and hydrosphere. The flowchart that has been designed visually illustrates a systematic process flow, facilitating understanding, analysis, and development of media design. The designed storyboard consists of 15 storyboards that describe the visual of the design development concept. The resulting media support elements include 3D objects, marker images, user interface (UI) elements, learning videos, and audio narration. The process of designing media support elements is shown in Figure 1.

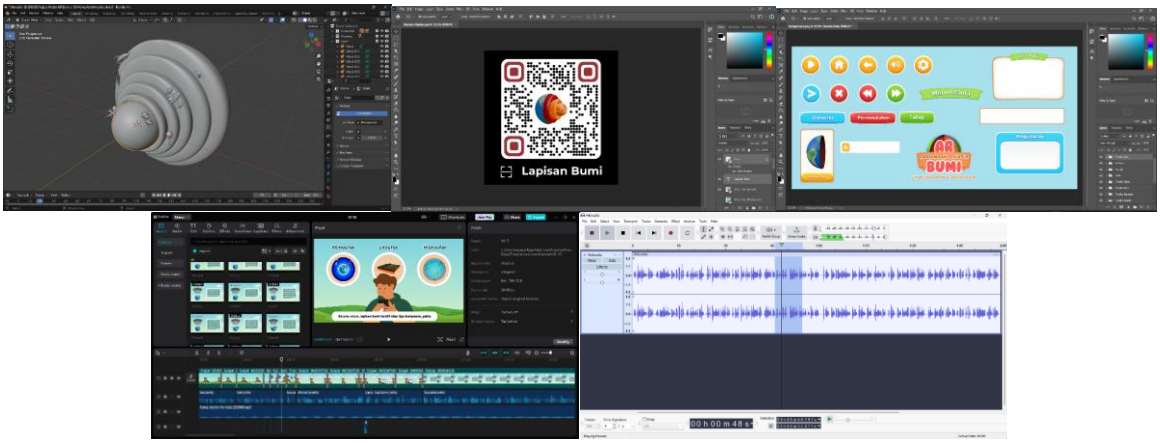


**Figure 1.** Design of Supporting Elements

The Development stage produces a media design that is compiled based on the flowchart and the storyboard that have been compiled. All elements designed at the Design stage are compiled into one unit. AR media development based on problem-solving uses the Unity 2022.3.47f1 software Windows version with the Vuforia 29.10.6 plugin. The Vuforia plugin is needed to import the marker database so that it can be used to track markers and recognize 3D objects. The Development of problem-solving-based AR interactive media combines elements and resources designed in separate scenes. The development process produces 27 scenes, which are then connected through coding. The media and coding development process in Figure 2.

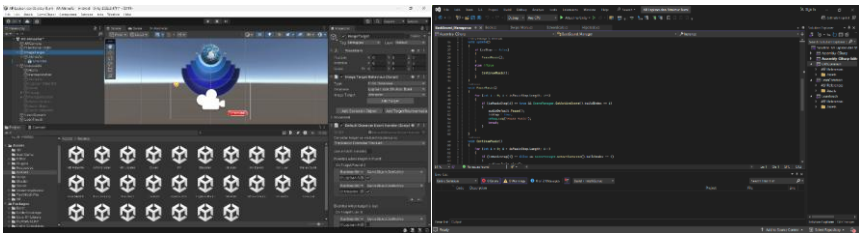

**Figure 2.** Development AR Media and Coding Process

The AR media results were exported in an Android application file with a 292 MB apk extension. The resulting media can operate on smartphones with minimum specifications on the Android 8.0 (Oreo) system. AR interactive media can operate on smartphones with ARMv7 or ARM64 architecture systems without needing Google AR Core support to operate in a broader range of smartphones. The AR interactive media development results are shown in Figure 3.


**Figure 3.** Media Development Results

During the development phase, a questionnaire instrument is also designed to test the validity and practicality of the product. Based on expert judgment, the developed questionnaire instrument received a validity coefficient of 1.00 with a very valid category. This indicates that the designed questionnaire instrument is very valid for measuring the aspects. After testing the validity of the questionnaire instrument, the AR interactive media's validity was tested, including validity testing by material experts and media experts. The validity testing results by material and media experts are shown in Table 6 and Table 7.

**Table 6.** Material Expert Validation Results

| Item | Expert | | $S_1$ | $S_2$ | $\sum s$ | n(c-1) | V | Criteria |
|---|---|---|---|---|---|---|---|---|
| | I | II | | | | | | |
| Item 1-10 | 38 | 40 | 28 | 30 | 58 | 60 | 0.97 | Very High |

**Table 7.** Media Expert Validation Results

| Item | Expert | | $S_1$ | $S_2$ | $\sum s$ | n(c-1) | V | Criteria |
|---|---|---|---|---|---|---|---|---|
| | I | II | | | | | | |
| Item 1-20 | 78 | 79 | 58 | 59 | 117 | 120 | 0.98 | Very High |

These results, based on Table 6 and Table 7, show that the developed AR interactive media is feasible for use in learning. After being declared valid, AR interactive media was tested for practicality through individual, small group, and teacher practicality trials. The results of the AR interactive media practicality test are in Table 8.

**Table 8.** Practicality Test Results

| No. | Trials Subject | Percentage | Criteria |
|---|---|---|---|
| 1 | Individual trials | 91.67% | Very Practical |
| 2 | Small group trials | 92.22% | Very Practical |
| 3 | Practically trial by teacher | 98.75% | Very Practical |

Based on the practicality test results in Table 8, the AR interactive media is categorized as very practical, meaning it is easy to use and attractive for students and teachers in the classroom. The next step is implementation. The Implementation stage results in an assessment of the effectiveness of AR interactive media in improving student learning outcomes in authentic learning situations. The effectiveness of problem-solving-based AR interactive media is tested by implementing the media in the learning process and conducting tests with a one-group pretest-posttest design. The implementation of media in learning, pre-test, and post-test was attended by all fifth-grade students of SDN 8 Mas, totaling 19 people. In analyzing the effectiveness of problem-solving-based AR interactive media in enhancing students' learning outcomes, a normality test was conducted as a prerequisite test, and a paired samples t-test was used to test the research hypothesis. Data from students' pre-test and post-test results were then analyzed to ensure data normality and test the research hypothesis. The normality test of students' pre-test and post-test data can be seen in Table 9.

**Table 9.** Normality Test Results of Pretest and Posttest Data

| Tests of Normality | | | | | | |
|---|---|---|---|---|---|---|
| | Kolmogorov-Smirnov | | | Shapiro-Wilk | | |
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Pre_Test | 0.203 | 19 | 0.039 | 0.932 | 19 | 0.188 |
| Post_Test | 0.201 | 19 | 0.041 | 0.925 | 19 | 0.139 |

Based on the normality test results conducted with IBM SPSS Statistics 30 for Windows software, the Shapiro-Wilk column shows that the significance value of the pretest data is 0.188, and the pretest data is 0.139. The values of Sig were 0.188 and 0.139 > 0.05. It can be concluded that both data groups are normally distributed. After the data is concluded to be normally distributed, hypothesis testing is then carried out with the paired sample t-test in Table 10.

**Table 10.** Paired Sample t-Test Result

| Paired Samples Test | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Paired Differences | | | | | t | df | Significance | |
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | One-Sided p | Two-Sided p |
| | | | | | Lower | Upper | | | | |
| Pair 1 | Pre_Test Post_Test | -26.316 | 9.074 | 2.082 | -30.689 | -21.942 | -12.641 | 18 | <0.001 | <0.001 |

Based on the paired sample t-test results conducted with IBM SPSS Statistics 30 for Windows software in Table 10, the two-sided p-significance value is <0.001. It can be seen that the Sig. <0.05 which indicates that $H_0$ is rejected and $H_1$ is accepted. There are differences in the learning outcomes of IPAS material on the layers and structure of the Earth for grade V students before and after using problem-solving-based AR interactive media. Based on the results of this analysis, problem-solving-based AR interactive media on the layers and structure of the Earth in fifth-grade elementary school is effectively used to enhance student learning outcomes. Finally, the evaluation stage produces feedback on the entire development stage, which becomes a reference for improving the media and drawing conclusions about the development process.

## Discussion

This research produces interactive media based on Augmented Reality (AR) with a problem-solving approach for the material of the layers and structure of the Earth in fifth-grade elementary school, which can be used on Android smartphones. For optimal AR performance, the device should run at least on Android Oreo and maintain ARMv7 and ARM64 architecture enabled throughout the development process to overcome the constraints of Google AR Core support (Rachman & Awab, 2024; Westfahl et al., 2022). Problem-solving-based AR interactive media contains 27 scenes connected by coding. It is developed by combining multimedia elements, including 3D objects, 2D images, text, video, and audio. The results of the research data analysis show that the problem-solving-based AR interactive media developed is very valid and practical for use in the classroom learning process and effectively enhances students' learning outcomes.

The media are designed as interactive media combining multimedia elements such as 3D objects, 2D images, text, video, audio, and quizzes to make problem-solving-based AR media more engaging and interactive. Using multimedia elements in AR media has enhanced interactivity and visual appeal (Aswan, 2024; Safira & Nahdi, 2024). Using multimedia elements in interactive media engages students to actively participate in learning according to their learning styles (Lubis, 2024; Sari et al., 2024). This allows students to learn and understand the material according to their abilities and preferences, thus enabling more effective learning. Using problem-solving-based AR interactive media is also not time-consuming because the media swiftly responds to marker images and is not affected by light intensity. This is inseparable from creating a database that keeps the marker image features high. Good stability of marker image

detection allows for smoother interaction, and students can explore virtual objects from different angles without losing track of marker images, making the learning experience more effective (Sulistiyono et al., 2024; Syahputra et al., 2024).

Problem-solving-based AR interactive media that is highly accurate in detecting marker images allows users to easily access 3D objects without experiencing delays or interruptions in scanning. This provides users with a good user experience in observing, analyzing, and zooming in and out of 3D models as a visualization of real objects displayed through a smartphone screen. Interactive AR media based on problem-solving will also be developed with a user-friendly and easy-to-use display so that it can be practically used by teachers and students in the learning process. Practicality of AR media is directly related to perceived usefulness and ease of use (Garzón et al., 2020; Ghobadi et al., 2022). The statement shows that practicality in AR media development is very crucial because students and teachers tend to use learning media that are easily accessible, do not require complicated technical steps, and meet their daily learning needs. Integrating the problem-solving method in the development of AR interactive media also contributes to enhancing students' learning outcomes. The problem-solving method can challenge students to discover new knowledge, increase student activeness in learning, and help students transfer knowledge (Fitrisyahni & Ningsih, 2023; Pradnyana & Rahayu, 2023). Combining AR media and problem-solving methods in learning can improve students' problem-solving skills, positively impacting student learning outcomes (Hui et al., 2024).

Previous research on AR media development has been conducted. This problem-solving-based AR interactive media development research results are highly related to prior research. AR media has been developed by combining 3D, text, video, quiz, and audio elements with valid and practical qualifications (Wibowo et al., 2022). In addition, AR media on the earth layer material was feasible for use in the earth layer learning process (Deli, 2020; Isty et al., 2021). Furthermore, AR media enhanced students' learning outcomes (Pramesila, 2022; Umri et al., 2023). These findings indicate that the AR-based interactive media developed in this study supports the broader trend in educational research, where AR technology enhances engagement and facilitates deeper understanding. The alignment of this study's results with previous research reinforces the argument that AR media, when designed appropriately, can serve as a powerful tool in education. From a theoretical perspective, this is strongly supported by Mayer's Cognitive Theory of Multimedia Learning, which posits that well-designed multimedia materials can enhance learning by optimizing cognitive load and facilitating dual-channel processing (Ali & Yahaya, 2022; Çeken & Taşkın, 2025). Additionally, the effectiveness of AR in enhancing learning outcomes can be analyzed through the lens of Piaget's and Vygotsky's Constructivist Learning Theory (Sanjaya et al., 2024; Yogaswara, 2024), which emphasizes active learning and meaningful knowledge construction. AR provides an experiential learning environment that enables students to explore abstract concepts through visualization, interaction, and real-time feedback, fostering a deeper understanding of the subject matter. Research shows that interactive and problem-solving-based learning approaches significantly enhance student engagement and cognitive development.

Overall, this research has made a significant contribution to educational innovation. The novelty introduced in this research by integrating the problem-solving method into AR interactive media effectively adds to the utility of AR interactive media. This research has implications for developing AR interactive media in educational science. It enriches the literature on integrating AR technology and learning methods in education. This research also has implications for developing a more innovative, interactive, and problem-solving-based IPAS learning strategy by utilizing AR interactive media as an effective learning tool in improving student understanding and learning outcomes. This research has certain limitations in its implementation. It focuses solely on developing AR interactive media that operates on smartphones with the Android operating system and is specifically designed to enhance students' learning outcomes. Based on these limitations, future research is recommended to expand AR media development beyond Android applications, such as iOS, Windows, web-based platforms, and other similar systems. Additionally, future research is encouraged to explore the development of AR media that enhances cognitive aspects, such as learning outcomes, and contributes to affective and psychomotor aspects of student development.

## 4. CONCLUSION

This research successfully developed problem-solving-based AR interactive media that is valid, practical, and effective in enhancing students' learning outcomes. This media can be run on smartphones with the Android operating system. It is developed by combining multimedia elements such as 3D objects, text, audio, video, and 2D images. The novelty of this research is integrating problem-solving methods in AR interactive media, unlike previous researchers who developed AR media without using appropriate learning methods. This research has implications for developing AR interactive media in educational science. It enriches the literature on integrating AR technology and learning methods in education to enhance students' learning outcomes. While this research focuses on developing AR interactive media for Android devices to enhance learning outcomes, future research can expand the development of AR interactive media for other system operations and explore the development of AR media that not only enhances students' learning outcomes.

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