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Integrating augmented reality with the e-IM3 structured thinking model to enhance problem-solving skills and learning interest in elementary spatial geometry

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Abstract

This study addresses the need to improve fifth-grade students' problem-solving skills and learning interest in spatial geometry—a topic often perceived as abstract and challenging—by developing an Augmented Reality (AR)-based instructional medium integrated with the e-IM3 (intelligent, meaningful, mindful, joyful) model. Grounded in the ADDIE framework, the research encompassed the analysis, design, development, implementation, and evaluation phases at SDN Kwadungan Lor, Ngawi, East Java. Initial analysis via diagnostic tests and teacher interviews confirmed low baseline performance and motivation levels. The resulting AR-e-IM3 media underwent expert validation and readability testing, achieving high validity scores (media: 3.79; problem-solving instrument: 3.42; and interest instrument: 3.98). A limited trial (n = 10) and a large-scale trial (n = 32) demonstrated strong practicality (88% and 84.5%, respectively). Effectiveness was evidenced by moderate N-Gain improvements in problem-solving skills (0.58 and 0.51) and learning interest (0.63 and 0.51). These findings indicate that the AR-e-IM3 integration successfully fosters engagement and meaningful learning, aligning with Generation Alpha's digital learning preferences. This study underscores the potential of technology-enhanced affective–cognitive models in elementary mathematics education. The implications include the scalable adoption of such media to strengthen 21st-century competencies—particularly critical thinking, spatial reasoning, and intrinsic motivation—while supporting curriculum innovation in resource-constrained settings.

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Introduction

Problem-solving skills are essential in mathematics learning and should be nurtured from the primary school level, as they play a crucial role in everyday life and must be mastered by every student (Susanto et al., 2024). The National Council of Teachers of Mathematics (NCTM) emphasizes that problem solving is not only the main goal of mathematics learning, but also serves as an important approach to help students build knowledge and apply it in real life (Koirala et al., 2008; Santos-Trigo, 2024). In an ideal situation, elementary school students are expected to have good logical reasoning and spatial understanding skills, enabling them to solve mathematical problems creatively and contextually.

However, the reality in the field shows that elementary school students still experience various difficulties in solving math problems that require logical reasoning and the ability to visualize three-dimensional objects, especially in spatial geometry (Hetmanenko, 2024; Kusuma et al., 2024). Low understanding of the shapes and properties of solid figures, limited ability to visualize objects as a whole, and lack of real-world experience in learning often result in students failing to grasp concepts deeply. This condition is exacerbated by students' low interest in mathematics, which affects their motivation and engagement in learning (Ariska et al., 2018; Hsiao et al., 2018; Nizami & Mahmudi, 2018). Therefore, teachers need to design learning activities that encourage students to actively explore various ways of solving real-world problems, thereby enhancing their motivation and engagement in learning (Rahayu & Kusuma, 2019).

The main problem is the lack of learning media that help students understand spatial concepts in a realistic, interactive, and in-depth way. Students are not yet accustomed to following stages of reflective and evaluative thinking when solving problems. As a result, their critical and creative thinking skills have not developed optimally. This shows the need for a learning approach that guides students to think in a structured way and that facilitates concrete visualization of spatial concepts. With advances in digital technology, Augmented Reality (AR) has emerged as an innovative learning tool. AR can display three-dimensional objects realistically and interactively on digital devices (Gargrish et al., 2020; Richardo et al., 2023). Research indicates that AR helps students understand spatial concepts more easily, strengthens visualization skills, and increases motivation and engagement in learning (Cevahir et al., 2022; Trilaksono et al., 2018). Developing critical thinking and problem-solving skills also requires a structured cognitive framework, such as the e-IM3 structured thinking model. Its steps are: identifying problems (*Identifikasi masalah*), building ideas (*Membangun ide*), clarifying ideas (*Mengklarifikasi ide*), and evaluating the validity of ideas (*Menilai kewajaran ide*), implemented electronically (Murtafiah, 2024). This model has been shown to guide students through reflective and evaluative stages and to improve mathematics learning outcomes (Masfingatin et al., 2024; Mesghina et al., 2024; Rahman et al., 2022).

Previous studies support the effectiveness of AR technology and the e-IM3 model in mathematics learning. Research on AR has shown that it effectively helps students visualize complex geometric shapes, enhances spatial understanding, and motivates them to engage in

self-directed learning (Ibáñez & Delgado-Kloos, 2018). The integration of AR with problem-based learning activities also encourages students to actively explore mathematical concepts and ideas (Garzón & Acevedo, 2019). From a theoretical perspective, the combination of AR and e-IM3 is strongly aligned with constructivist learning theory, which posits that learners construct knowledge actively through interaction with meaningful contexts. AR provides immersive and manipulable environments that allow students to explore geometric relationships in real time, fostering deeper conceptual understanding. The e-IM3 model complements this by guiding learners through structured phases of exploration, analysis, and reflection core principles of constructivist pedagogy (Kolil et al., 2025). Meanwhile, research on the application of the e-IM3 model also demonstrates improvements in critical thinking and problem-solving skills through systematic thinking steps. However, most studies have only examined the application of AR or structured thinking models separately, without integrating both within the context of spatial geometry learning at the elementary school level.

The novelty of this study lies in the direct integration between Augmented Reality-based media and the e-IM3 model, which was systematically developed to enhance students' problem-solving abilities and interest in learning mathematics. The integration of AR and e-IM3 is expected to provide mindful, meaningful, and joyful learning (Feriyanto & Anjariyah, 2024). This approach is particularly relevant to the learning characteristics of Generation Alpha, who are growing up immersed in digital environments and exhibit strong preferences for interactive, visual, and technology-enhanced learning experiences (Höfrová et al., 2024; Ziatdinov & Cilliers, 2021). Additionally, the combination of the two is believed to provide students with a more concrete, active, and meaningful learning experience (Schutera et al., 2021). Based on the above issues, the objective of this study is to develop an Augmented Reality Media learning tool based on the e-IM3 model to enhance problem-solving skills and learning interest among elementary school students in spatial geometry.

Methods

This study employed a research and development method, guided by the five-step of ADDIE model. This study employed a research and development method, guided by the five-step ADDIE instructional design model: Analysis, Design, Development, Implementation, and Evaluation (Molenda, 2003; Spatioti et al., 2022). The ADDIE model was selected for its structured and iterative approach to instructional design, which facilitates systematic development of educational media while remaining adaptable to user needs and technological contexts (Abuhassna et al., 2024). It emphasizes continuous refinement through feedback loops, ensuring that each phase builds upon the previous one to produce effective and learner-centered outcomes.

In the Analysis stage, researchers examined students' problem-solving abilities, learning interests, curriculum demands, and the availability of teaching materials. This phase provided a foundation for understanding learner characteristics and instructional gaps. The Design phase focused on formulating clear instructional goals and selecting appropriate digital strategies,

including augmented reality and the e-IM3 learning model, to support spatial geometry learning. During the development stage, prototypes of AR-based media were created using Unity, integrating interactive 3D content aligned with the e-IM3 framework. These prototypes underwent expert validation and readability testing to ensure content accuracy, usability, and pedagogical relevance. The Implementation stage involved classroom trials with elementary students, allowing them to engage directly with the media while researchers observed their interactions and collected feedback. Finally, the evaluation stage assessed the effectiveness of the media in improving students' problem-solving skills and learning interest using validated instruments. This phase emphasized both formative and summative evaluation, aligning with best practices in instructional design (Abuhassna et al., 2024; Molenda, 2003). The ADDIE model's flexibility and emphasis on learner-centered design make it a robust framework for developing innovative educational technologies in diverse learning environments in Figure 1.
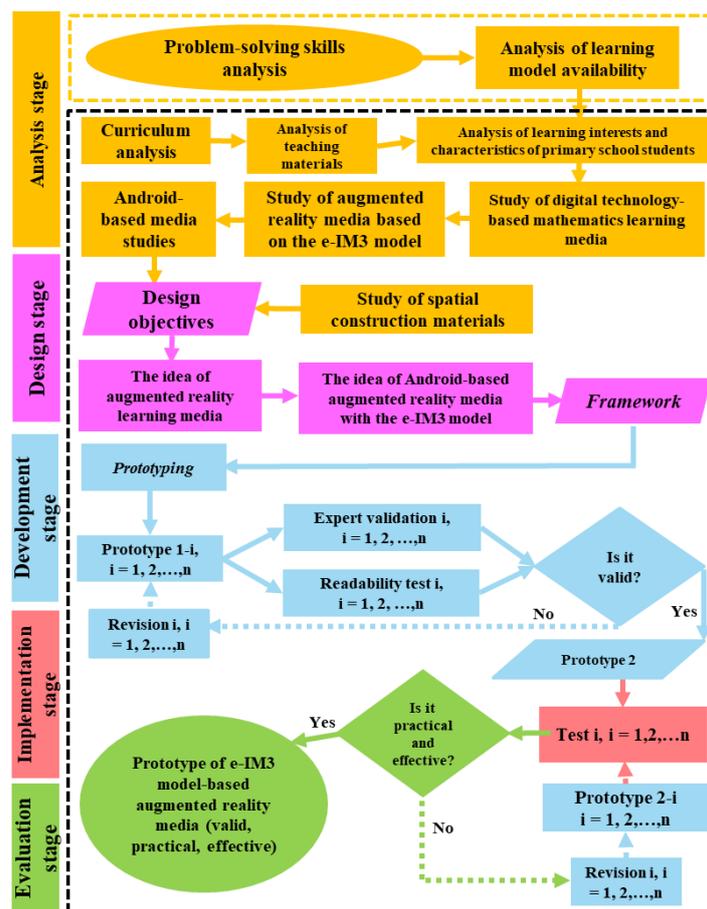

Figure 1. Research activity flow

The explanation of the research process is as follows. The analysis stage includes: 1) analysis of problem-solving abilities and 2) analysis of the availability of learning models. Furthermore, it is necessary to conduct an analysis related to the current curriculum requirements, learning interests, characteristics of elementary school students, and analysis of the availability of teaching materials. During the analysis stage, researchers will: 1) a review of

mathematics learning media, 2) a review of augmented reality media, 3) a review of spatial geometry materials, and 4) a review of the digitization of teaching materials, followed by the establishment of design objectives. In the design stage, the researcher will carry out activities that include: 1) establishing ideas for the design of new learning media, 2) establishing ideas for the design of augmented reality media, and 3) establishing an augmented reality media framework based on the e-IM3 model. During the designs stage, the researcher will carry out activities including: 1) designing an augmented reality media prototype based on the e-IM3 model to obtain prototype 1, 2) designing an augmented reality media prototype based on the e-IM3 model to obtain prototype 1, 3) designing validation instruments and readability tests. In the development stage, expert validation and readability tests until a valid prototype is obtained (prototype 2).

Validation will be conducted by 1 expert in mathematics education and 2 experts in digital learning media, with validity indicators if the average results of the validity and readability tests with a threshold of greater than 3.00 on a Likert scale of 1 to 5. This threshold aligns with international standards for instructional media validation, where expert judgment is used to assess content accuracy, technical feasibility, and pedagogical relevance. According to Safei et al. (2019), instructional materials are considered valid when expert evaluations yield average scores above 3.0 on a 4-point scale, indicating strong alignment with learning objectives and usability criteria. Similarly, Shakeel et al. (2023) emphasize that expert validation is a critical component of the ADDIE model, ensuring that media design meets both subject-matter and technological standards before classroom implementation. In the implementation stage, limited trials and extensive trials were carried out. In the evaluation stage, researchers will carry out activities that include: 1) testing augmented reality media based on the e-IM3 model to improve students' problem-solving abilities and interest in learning, 2) analyzing and evaluating the test results until the final prototype is obtained. Practicality was evaluated through student response questionnaires, focusing on indicators such as interest, ease of use, visual appeal, conceptual support and willingness to reuse and effectiveness are assessed based on the N-Gain value derived from students' pre-test and post-test problem-solving scores, as well as their responses on the learning interest questionnaire. N-Gain is widely used in educational research to quantify the extent of learning improvement and the instructional impact of an intervention. According to Navarrete et al. (2024), N-Gain values ranging from 0.3 to 0.7 indicate moderate learning gains and are particularly effective for evaluating technology-enhanced learning environments. To measure the effectiveness of the developed media, this study applies the Normalized Gain (N-Gain) formula. This calculation provides a standardized measure of learning progress, allowing researchers to categorize the effectiveness of the media into low, moderate, or high based on the resulting N-Gain score.

Results

The results of the research on the development of augmented reality media based on the e-IM3 model to improve students' problem-solving skills and interest in learning are as follows.

Analysis stage

The analysis stage began with a comprehensive investigation into students' problem-solving abilities, curriculum demands, and the availability of instructional resources. Diagnostic tests, classroom observations, and teacher interviews revealed that students struggle significantly with contextual mathematics problems, particularly in the stages of understanding the problem and formulating solution strategies. Teachers confirmed that they rarely use systematic problem-solving approaches and tend to rely on traditional lecture and question-answer methods. Moreover, spatial-based learning models such as Augmented Reality (AR) have not yet been implemented, and most teaching media remain limited to printed textbooks. This teacher-centered approach contributes to a monotonous and non-interactive learning experience.

To address these challenges, researchers conducted a literature review on mathematics learning media, AR technology, spatial geometry content, and the digitization of teaching materials. Learning media play a vital role in stimulating students' thinking, attention, and motivation, thereby enhancing conceptual understanding (Arsyad, 2019; Aulia & Prahmana, 2022). Interactive, technology-based media have been shown to improve students' grasp of abstract spatial concepts through digital visualization (Khotimah & Hafidz, 2025). AR, in particular, integrates two- or three-dimensional virtual objects into the real environment in real time, enabling dynamic interaction between learners and digital content (Alfitriani et al., 2021; Scott, 2015; Setiawan & Nurfadilah, 2024). International studies support this approach: AR has demonstrated a medium-to-high positive effect on mathematics achievement in K–12 students, especially when virtual objects are well-integrated into the learning experience (Flavin et al., 2025).

Solid geometry is a foundational topic in mathematics education, essential for developing students' spatial reasoning and understanding of three-dimensional objects. It involves measurable volumes and distinctive features such as sides, edges, and vertices (Lestari & Karlimah, 2017; Pangestu & Ruqoyyah, 2023; Ruseffendi, 2005). International research also highlights the importance of AR in geometry education, noting its ability to enhance visual thinking and reduce cognitive barriers (Bulut & Borromeo Ferri, 2023).

In parallel, the digitization of teaching materials has emerged as a strategic innovation in education. It enables flexible access to content via digital devices and supports interactive, student-centered learning environments (Khairunnisa, 2024; Schmid et al., 2023). Globally, digital transformation in education is recognized as a key driver of equity and engagement, especially when combined with immersive technologies like AR. These findings underscore the need to develop AR-based digital media tailored to spatial geometry, aligned with student needs and curriculum goals.

Design stage

The design stage focused on generating concrete solutions in the form of instructional media concepts. Researchers began by identifying student challenges in understanding spatial geometry, particularly the lack of reflective and evaluative thinking during problem-solving. These cognitive limitations hinder the development of students' critical and creative thinking skills, which are essential for mastering spatial concepts.

To address these issues, the idea emerged to develop Augmented Reality (AR) based e-IM3 media capable of visualizing abstract mathematical concepts in a realistic and interactive manner. AR was selected due to its ability to present three-dimensional learning objects and its compatibility with students' widespread use of smartphones, making it both accessible and engaging. Following this, researchers constructed a framework for the AR based e-IM3 media. This framework includes: 1) Structuring content specifically for spatial learning, 2) Integrating mathematical material into AR objects, 3) Designing intuitive navigation to support user interaction. The Unity application was chosen as the development platform to implement this framework into an initial prototype. This prototype was designed to be ready for testing and iterative refinement. The prototype features two main components: 1) material menu to cover core concepts of three-dimensional shapes such as cubes, prisms, and pyramids, 2) e-IM3 solution menu to guide students through structured problem-solving steps including problem identification, idea generation, classification, feasibility assessment, and AR-based interaction. Additionally, the media includes practice questions with guided answers to reinforce learning and support independent exploration. The initial design layout is illustrated in Figure 2, which outlines the media structure and user interface.
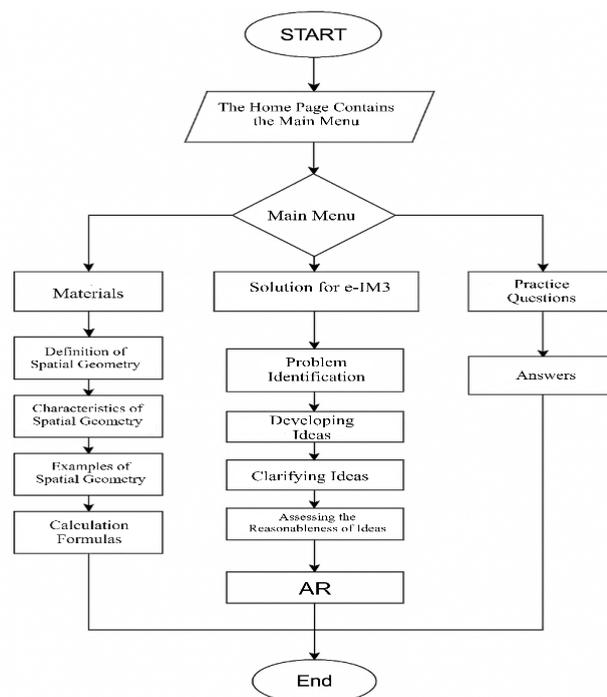

Figure 2. Flowchart of augmented reality media e-IM3-based media

Development stage

The development stage was carried out to develop, test, and validate the Augmented Reality based e-IM3 media prototype. In this stage, researchers carried out four main activities. They designed the augmented reality based e-IM3 prototype to obtain the prototype. Researchers began to develop the initial design of the media by implementing the framework that had been established in the ideate phase. The design process was carried out using the Unity application to integrate learning materials into an interactive 3D visual format, resulting in an initial prototype. The design process involves developing an augmented reality-based e-IM3 media prototype, referred to as Prototype 1, which serves as the initial implementation of the AR learning tool. This prototype integrates the e-IM3 model framework with augmented reality features to support structured, interactive, and visually enriched mathematics learning. This prototype serves as an internal test product to determine how well the design aligns with student needs. Documentation of the prototype design is shown in Figures 3 and 4.
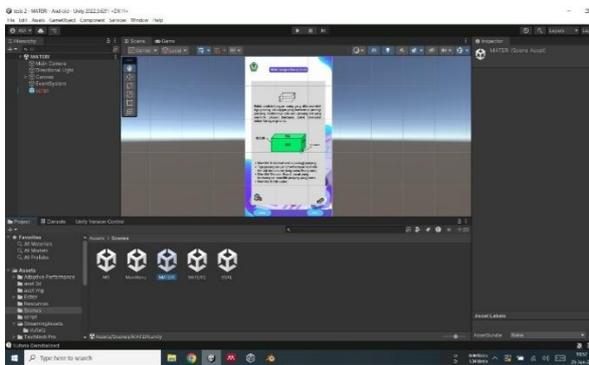

Figure 3. Designing the display of spatial construction materials
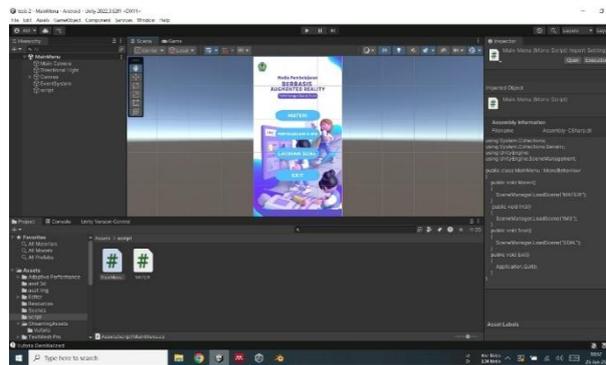
Figure 4. Designing the initial display of media

To design a validation instrument so that augmented reality media can be assessed objectively, researchers developed a validation instrument for student problem-solving instruments, a validation instrument for student learning interest, and a readability test for the developed media. Expert validation and readability testing were conducted until a valid prototype was obtained (prototype 2). The prototype was then validated in terms of content, language, and construction by 1 expert in mathematics education and 2 experts in digital learning media. Based on the validation results, the researchers made revisions to obtain Prototype 2, which was valid and ready for testing in the next phase. The validation results consist of validation of the Augmented Reality media based on e-IM3, validation of the student problem-solving instrument.

## Validation and readability testing of augmented reality media based on e-IM3

The AR application was validated based on four main aspects, namely content/material feasibility, media/display design, technical feasibility, and learning (e-IM3). This validation involved three validators and resulted in a combined average score of 3.79, which also falls into the "Highly Valid" category".

Table 1. Average value of AR media validation

Aspect	Validator 1	Validator 2	Validator 3	Total Average
Content/Material Feasibility	4.0	3.25	3.25	3.5
Media/Display Design	4.0	4.0	4.0	4.0
Technical Feasibility	4.0	4.0	4.0	4.0
Learning (e-IM3)	4.0	3.5	3.5	3.67
Overall Average	4.0	3.69	3.69	3.79

Table 1 shows that the media/display design and technical feasibility aspects received a perfect score (4.0) from all validators, indicating that the application has an attractive interface, easy navigation, and functions very stably without technical problems. In terms of content/material feasibility, the average score is 3.5. This is due to feedback from Validator 1 and Validator 2, who suggested adding more content to make it more comprehensive. In terms of learning (e-IM3), the average score is 3.67, with a note from the validator regarding the need to add AR elements to support deeper student exploration. Additionally, there were suggestions to provide alternative visual representations of spatial structures to enhance students' problem-solving skills and ease of access to the media.

In addition to expert validation results, readability tests were also conducted to determine the responses of teachers and students. Teachers and students provided feedback regarding the display colours, which were initially dark but became more colourful in line with the characteristics of primary school students. All feedback from validators and the results of the readability test were followed up by revising the application to improve the quality of the material and interactivity of learning, resulting in prototype 2 in Figure 5.
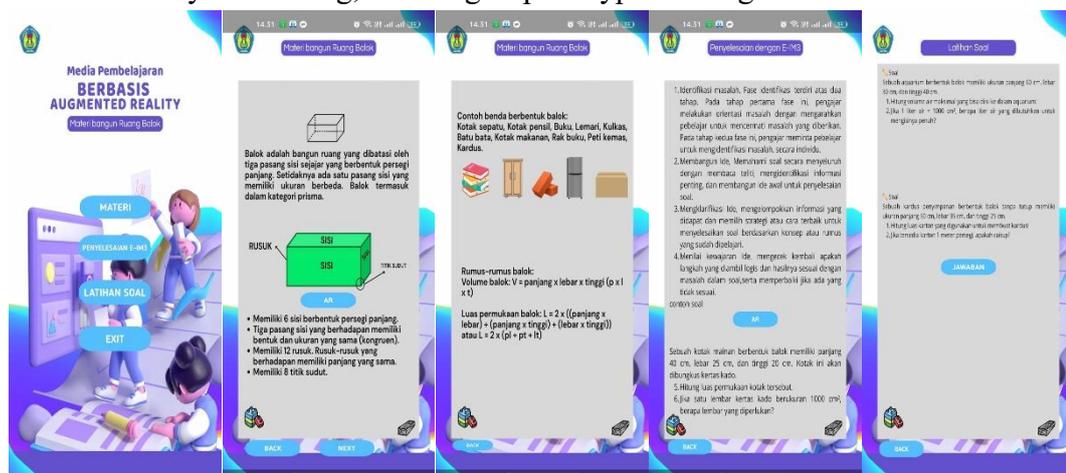
Figure 5. Display and media content on prototype 2

Validation of student problem-solving instruments

The problem-solving ability instrument was validated by three validators focusing on content, language, and question appropriateness. The validation results showed a high level of validity with a combined average of 3.42, which falls into the 'Highly Valid' category".

Table 2. Average value of problem solving instrument validation results

Aspect	Validator 1	Validator 2	Validator 3	Average Total
Contents	3.5	3.75	3.5	3.58
Language	3.0	3.25	3.75	3.33
Appropriateness	3.0	3.5	3.5	3.33
Overall Average	3.17	3.5	3.58	3.42

In Table 2, validator 1 gave an average score of 3.17, with a special note on the Polya indicator, which was considered unclear. Validator 2 gave an average of 3.5, with suggestions for adjustments to the wording of the questions and the assessment rubric. Meanwhile, validator 3 gave an average of 3.58 with an important note regarding questions that require an understanding of spatial logic. Despite some notes from the validators, the questions are generally considered relevant, have adequate language, and align with the learning objectives. The notes and suggestions provided have served as the basis for improvements to refine the instrument, particularly regarding the completeness of the assessment rubric and the clarity of more specific questions.

Validity of student learning interest instruments

The student learning interest questionnaire was validated by three experts to ensure its validity in terms of content, language, and construction. The validation results showed a very high degree of consistency among the validators. Validator 1 and Validator 2 assigned an average overall validation score of 3.97, while Validator 3 assigned a score of 4.0. This resulted in an average combined validity score of 3.98, which falls into the 'Highly Valid' category.

Table 3. Average Values of Learning Interest Instrument Validation Results

Aspect	Validator 1	Validator 2	Validator 3	Average Total
Content	4.0	4.0	4.0	4.0
Language	3.9	3.9	4.0	3.93
Construction	4.0	4.0	4.0	4.0
Overall Average	3.97	3.97	4.0	3.98

In Table 3, the content and construction aspects received a perfect average score (4.0) from all validators, indicating that the statements in the instrument are relevant to the indicators of learning interest and are formulated appropriately. Although there was some feedback on the language aspect from two validators (score 3.9), the overall average for this aspect remained high (3.93), indicating that the language used is already very good and easy for students to

understand. The feedback provided, such as editorial adjustments to certain statements, has been addressed to enhance the clarity of the instrument.

Implementation stage

The implementation stage was conducted to assess the final prototype of the Augmented Reality-based e-IM3 learning media in a real classroom setting. The initial limited trial was carried out at a partner elementary school involving 10 fifth-grade students. During this stage, students interacted directly with the media while researchers provided guidance and observed their responses. Evaluation instruments included a learning interest questionnaire, a spatial geometry problem-solving test, and structured observation sheets. These tools were used to measure key indicators of effectiveness such as student engagement, conceptual understanding, and the ability to solve spatial problems.

Following the limited trial, a large-scale classroom implementation was conducted with 32 fifth-grade students to further validate the media's effectiveness across a broader learner population. This phase allowed researchers to observe variations in student interaction, engagement levels, and learning outcomes in a more diverse setting. The results showed a marked improvement in both learning interest and problem-solving performance compared to the pre-test. While Figures 6 and 7 visually document student interaction and researcher facilitation, the core findings are supported by quantitative data and qualitative observations collected during both trial

The implementation phase aims to test the final prototype of the e-IM3 model-based Augmented Reality media through implementation testing at partner schools, evaluate its effectiveness, and make final improvements to obtain a final prototype that is ready for use. Documentation of the implementation stage can be seen in Figures 6 and 7.

Figure 6. Students trying out the media

Figure 7. Researchers assisting students using media

Evaluation stage

At this evaluation stage, the researchers explained in detail the results of the implementation stage, namely student's problem-solving skills and the result of the learning Interest questionnaire are as follows. The evaluation phase also focused on assessing the practicality of the Augmented Reality-based e-IM3 model learning media through student response questionnaires administered during both the limited trial involving 10 students and the large-scale classroom trial involving 32 students. In addition, the effectiveness of the media was

examined through the results of the student's problem-solving skills test and the learning interest questionnaire.

Practicality of the augmented reality-based e-IM3 model learning media

To evaluate the practicality of the Augmented Reality-based e-IM3 model learning media, researchers first conducted a limited trial involving 10 fifth-grade students, during which a structured student response questionnaire was administered. This was followed by a large-scale trial involving 32 fifth-grade students to assess the media's practicality in a broader classroom context. In both trials, students interacted directly with the media and completed the same questionnaire. The results from Table 4 show a average practicality score of 0.88 or 88% in the limited trial and average score of 0.845 or 85% from the large-scale trial. Furthermore, the majority of students responded with agree and strongly agree on the response questionnaires during both the limited and large-scale trials, demonstrating positive perceptions and high acceptance of the media. This suggests that media not only meets practical usability standards but is also well-received by students across different implementation scales. Both scores fall into the "very practical" category, indicating that the media was well-received by the majority of students. These findings reflect strong usability, visual appeal, and pedagogical value. The consistency of high scores across all indicators such as interest, ease of use, conceptual support, and willingness to reuse suggests that the e-IM3 model-based media is not only effective in small-group settings but also scalable and suitable for larger classroom environments. Similarly, Radu (2014) found that AR applications in education significantly enhance student motivation and usability when designed with intuitive interfaces and meaningful content

Table 4. Average practicality scores from student response questionnaires in limited trials and large-scale trial

N-Gain Score	Limited Trial	Large-Scale Trial
Average	0.88	0.845
Percentage	88%	85%
Category	Very Practical	Very Practical

Student's problem-solving skills

The results of the Augmented Reality-based e-IM3 model learning media trial showed an improvement in students' problem-solving abilities in block geometry. In addition, the effectiveness of the Augmented Reality-based e-IM3 model learning media was measured using the N-Gain test, calculated from pre-test and post-test scores during the implementation stage.

The N-Gain result from the limited trial involving 10 students was 0.5841 or 58.41%, which falls into the moderately effective category. Meanwhile, the large-scale classroom trial involving 32 students yielded an N-Gain score of 0.5088 or 50.88%, also categorized as moderately effective. These results are presented in Table 5.

Table 5. N-Gain results in limited trial and large scale trial

N-Gain Score	Limited Trial	Large-Scale Trial
Average	0.5841	0.5088
Percentage	58.41%	50.88%
Category	Moderately Effective	Moderately Effective

This classification is supported by recent research from Navarrete et al. (2024), which confirms that normalized gain remains a reliable metric for estimating learning rates and instructional effectiveness. Their study highlights that N-Gain values between 0.3 and 0.7 reflect moderate conceptual learning improvement, especially in technology-enhanced environments. The use of N-Gain continues to be a standard approach in evaluating conceptual growth in STEM and mathematics education, including AR-based interventions. These findings suggest that interactive technology-based learning approaches and systematic thinking structures can substantially enhance students' conceptual understanding and problem-solving skills, making AR-based e-IM3 an effective and impactful learning medium.

Result of the learning interest questionnaire

The results of the student learning interest questionnaire revealed a marked improvement in fifth-grade students' enthusiasm for mathematics, particularly in spatial geometry, following the implementation of the Augmented Reality-based e-IM3 learning media. This suggests that the previous instructional approach had limited impact on engaging students with the material. While the scoring system provides useful benchmarks, it's important to note that the increase reflects more than numbers. It suggests that interactive and immersive media can play a meaningful role in motivating learners and enhancing their connection to abstract mathematical concepts.

In addition to the questionnaire results, the effectiveness of the Augmented Reality-based e-IM3 model learning media was further supported by the N-Gain score obtained from pre-test and post-test learning assessments. The N-Gain score for student learning interest in the limited trial involving 10 students reached 0.6337 or 63.37%. Meanwhile, the large-scale classroom trial involving 32 students yielded an N-Gain score of 0.5111 or 51.11%. These results affirm that the AR-based e-IM3 media consistently improves student interest across different classroom scales, as shown in Table 6.

Tabel 6. N-Gain results of the learning interest questionnaire in limited trial and large scale trial

N-Gain Score	Limited Trial	Large-Scale Trial
Average	0.6337	0.5111
Percentage	63.37%	51.11%
Category	Moderately Effective	Moderately Effective

This classification is consistent with recent findings by Navarrete et al. (2024), who reaffirm that normalized gain values between 0.3 and 0.7 indicate learning improvement and are commonly used to evaluate the impact of instructional innovations, especially in technology-enhanced learning environments such as Augmented Reality. This improvement also proves that E-IM3 learning media with Augmented Reality technology is an effective tool that has substantially increased students' interest in learning, making them more motivated and enthusiastic in participating in the learning process.

Discussion

The use of Augmented Reality based with the e-IM3 model learning has been proven effective in improving students' problem-solving skills in spatial geometry. The results of the study show a significant increase in problem-solving indicators. These findings are in line with Radu (2014) which states that Augmented Reality-based learning can improve students' spatial and problem-solving skills through interactive learning experiences. The three-dimensional visualisation offered by augmented reality helps students understand abstract concepts more concretely, enabling them to plan and evaluate mathematical solutions, especially spatial geometry material, more systematically.

The integration of Augmented Reality (AR) with the e-IM3 model significantly enhanced students' spatial reasoning, problem-solving abilities, and learning interest. By externalizing abstract geometric concepts into interactive visual formats, AR reduced both intrinsic and extraneous cognitive load, supporting more efficient mental processing (Ibáñez & Delgado-Kloos, 2018; Mayer, 2009). Simultaneously, the e-IM3 model scaffolded metacognition through structured phases exploration, interpretation, modeling, and reflection that promoted self-monitoring and strategic thinking, consistent with Zimmerman (2002) theories. Beyond cognitive gains, the study revealed a marked increase in student motivation and engagement, with most learners shifting from low or moderate interest to high and very high categories after using AR media. This supports Akçayır and Akçayır (2017) findings that AR-based learning fosters active participation and creates a more engaging environment than conventional methods. Thus, AR not only functions as a visual aid but also as a powerful pedagogical tool that enhances comprehension, retention, and enthusiasm for mathematics learning. As Billinghurst et al. (2015) emphasize, augmented reality bridges the gap between the digital and physical worlds, enabling learners to interact with virtual information in real-time contexts, thereby transforming abstract understanding into tangible experience. This aligns with Hake (1998) assertion that interactive engagement approaches yield significantly higher learning gains than traditional, passive instructional methods, emphasizing the value of active student involvement in constructing knowledge.

The validation of learning media conducted by experts shows that Augmented Reality-based e-IM3 model has very high quality in terms of content, technical aspects, appearance, and learning. This confirms that the media developed is not only visually appealing, but also in line with effective pedagogical principles. Bacca et al. (2014) emphasises the importance of an

instructional design framework in the development of augmented reality applications so that they are aligned with learning objectives. With this validation, this learning medium is considered suitable for use in mathematics learning at the elementary level in spatial geometry material.

Various previous studies also support this research, which shows that the use of augmented reality can also enhance exploratory learning, thereby connecting virtual elements with real-world experiences (Cheng & Tsai, 2013; Dede, 2009). This is also in line with Anisa et al. (2024), which states that the use of virtual technology can make learning easier to understand, help students grasp the material more effectively, and reduce boredom in studying mathematics. The use of Augmented Reality allows students to observe phenomena that cannot be seen directly, thereby enriching the learning process. It has also been shown to enhance students' motivation and investigative skills, fostering critical thinking and problem-solving abilities in mathematics learning (Akbar et al., 2025). Therefore, Augmented reality based learning media integrated with the e-IM3 model can simultaneously improve problem-solving abilities and interest in learning (Dunleavy et al., 2009; Sotiriou & Bogner, 2008).

Conclusion

This study successfully developed an Augmented Reality (AR)-based learning media integrated with the e-IM3 structured thinking model to enhance fifth-grade students' problem-solving skills and learning interest in spatial geometry. The integration of AR technology with the e-IM3 model offers a mindful, meaningful, and joyful learning experience tailored to Generation Alpha learners. The development process followed the Design Thinking framework—empathize, define, ideate, prototype, and test/evaluation and resulted in a highly valid learning medium, as confirmed by expert validation scores of 3.79 for media and 3.98 for the learning interest instrument.

The implementation phase involved both a limited trial with 10 students and a large-scale trial with 32 students. In the limited trial, 50% of students achieved a high category in problem-solving skills, and 80% were categorized as high or very high in learning interest. The practicality score reached 0.88 (88%), while the N-Gain score for learning interest was 0.6337 (63.37%). In the large-scale trial, the practicality score was 0.845 (84.5%), and the N-Gain score for learning interest was 0.5111 (51.11%). These results indicate that the AR-based e-IM3 media is both practical and effective in fostering 21st-century competencies such as critical thinking, problem solving, and motivation in mathematics learning.

Despite its promising outcomes, the study has limitations. It focused on a single mathematical topic and involved a relatively small and localized sample. Future research should expand the scope to include broader mathematical content, larger and more diverse student populations, and long-term impact analysis. Further refinement of AR features and exploration of cross-curricular applications are also recommended to enhance the media's versatility and pedagogical value.

Author Contributions

Abas Maulana: Conceptualization, writing - original draft, editing, and visualization; **Wasilatul Murtafiah:** Writing - review & editing, formal analysis, and methodology; **Jefry Handhika:** Validation and supervision; **Joel I. Alvares:** Writing - review & editing.

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