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Augmented inquiry: developing AR-based media for spatial geometry in elementary schools

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Abstract

Mathematics learning on solid geometry topics in elementary schools still faces challenges in visualising abstract and spatial concepts. This study aimed to develop and examine the feasibility, practicality, and effectiveness of an Augmented Reality (AR) learning medium based on Inquiry Learning for fifth-grade elementary students on solid geometry material. This research employed the Research and Development (R&D) method. The research subjects consisted of two media experts, two subject-matter experts, two fifth-grade teachers, and 20 fifth-grade students at Purwosari Elementary School. Data collection instruments included expert validation questionnaires, teacher and student response questionnaires, and learning achievement tests administered through pretests and posttests. The results showed that the AR learning media was categorised as highly feasible by media experts with a percentage of 83.75% and by subject-matter experts with 88.33%. Teachers' evaluations indicated a highly practical category with a percentage of 87.6%, while students' responses showed a practical category with an average percentage of 75.60%. The effectiveness test revealed a significant improvement in learning outcomes, with a significance value of 0.000 (< 0.05) and an N-Gain score of 0.45, classified as moderate. The findings imply that AR-based Inquiry Learning media can serve as an innovative

alternative to enhance students' motivation, conceptual understanding, and mathematics learning outcomes in elementary schools.

INTRODUCTION

Background of the Study

Spatial geometry is one of the fundamental components of mathematics education, especially in elementary schools. Spatial geometry plays an important role in developing students' abilities to visualise, analyse, and manipulate objects in three-dimensional space (Govender & Amevor, 2025; Mandala et al., 2025). This is regulated in the Regulation of the Minister of Primary and Secondary Education Number 12 of 2025 concerning Content Standards, which regulates the scope of material and the level of competence of students at each level of education. These competencies include an understanding of geometry and spatial abilities in elementary school. This regulation provides a normative basis for teachers in developing and selecting learning media.

Teachers are encouraged to utilise various forms of media that are innovative, contextual, and appropriate to the needs of students. One of the efforts that teachers can use to help students visualise spatial objects is through learning media (Xu et al., 2024). One type of learning media that can be developed is Augmented Reality media, which can be used to visualize spatial objects in 3D. The benefits of Augmented Reality in learning are that it can increase student attention and make students feel satisfied with what they have learned (Flavin et al., 2025). Through the use of AR technology, geometric objects can be depicted realistically through 3D virtual modeling that is identical to the original objects (Rukayah et al., 2021). AR media provides a different learning experience, allowing students to gain relevant and broader learning experiences outside the classroom (Nadzeri et al., 2024). Augmented reality (AR) has emerged as a transformative tool in education, helping to visualize difficult-to-reach shapes and make them feel closer (Ismail et al., 2025). Ministry of Education and Culture Regulation No. 68 of 2014 explains that the use of ICT in learning supports exploration and active learning among students. Government regulations governing the implementation of learning are contained in Regulation of the Minister of Primary and Secondary Education Number 1 of 2026 concerning Process Standards, which emphasizes holistic learning with the principles of awareness, meaning, and enjoyment. This regulation directs educators to implement contextual, relevant, and student-centered learning.

Solid geometry material requires students to be able to describe every angle, side, and face of a solid geometry object in 3D (Mathias et al., 2024). The use of AR learning media significantly facilitates students in visualising the shape of solid geometry in a real and interactive way. AR media is a solution to overcome the spatial perception difficulties often experienced by students (Mandala et al., 2025; Nadzeri et al., 2024). In addition to learning media that support learning, teachers need to determine the learning steps to be taken. One learning model that teachers can use in determining the learning flow is inquiry learning.

The inquiry learning model is a learning process that aims to encourage students to instil the basics of scientific thinking by activating students to search for material concepts independently. The result of this learning method is that students can draw conclusions based on the information obtained in expressing existing concepts. Inquiry learning, on the other hand, encourages students' independent exploration through questions, hypotheses, and experiments, thereby fostering critical thinking (Jainan et al., 2025). In elementary school settings, these variables are interrelated to overcome visualisation barriers in geometry, where students struggle with spatial reasoning and the rotation of shapes.

Inquiry learning is a learning model that seeks to instil the basics of scientific thinking in students by actively involving. The inquiry learning model itself aims to improve students' ability to draw their own conclusions. With the inquiry learning model, students can actively participate in the teaching and learning process because they examine the validity of certain information created about the subject. The purpose of inquiry is to develop students' critical thinking skills in the learning process, thereby providing opportunities to improve learning outcomes (Parker et al., 2022). The use of the inquiry learning model in learning can reduce written teaching and learning activities so that students can play an active role in teaching and learning activities.

The Problem of the Study

Spatial thinking skills, such as visualisation and rotation, are very important for problem-solving in both mathematics and everyday situations. Based on an analysis of various research gaps that have been identified, spatial learning still faces a number of significant difficulties and problems from the educator's perspective. Differences in the level of understanding and spatial abilities pose a challenge in the process of learning spatial figures (Govender & Amevor, 2025; Mandala et al., 2025; Nadzeri et al., 2024). In addition, the presentation of abstract and contextual material hinders

the understanding of spatial figure concepts. The main problem in spatial learning lies in the lack of application of evidence-based learning approaches. Spatial learning still shows limitations in the application of differentiated learning (Çavuş & Deniz, 2022; Thom et al., 2024). This condition results in learning that is oriented towards procedural mastery rather than conceptual understanding.

Based on the researcher's observations at Purwosari Elementary School, the learning process tends to be minimal in the use of learning media. The majority of teachers still apply conventional lecture and note-taking learning models. This causes students to experience boredom during teaching and learning activities. This condition indicates that learning is passive with a centralisation of the teacher's role. This approach contradicts the principles of the Merdeka Curriculum implemented in the school. This principle emphasises active student involvement. The lecture approach also hinders students' understanding of complex material, such as three-dimensional object-based spatial structures. Verbal and written explanations on the blackboard have proven to be ineffective in helping students understand the concepts of spatial structures (Jainan et al., 2025; Xu et al., 2024).

Based on the observation results, it is known that student learning outcomes in spatial geometry material are still not optimal. This is evident from the average scores obtained in the spatial geometry material, which have not reached the minimum completion criteria. Based on the observation results, the number of students who have achieved completion is 8 students (34.78%), and the number of students who have not achieved completion is 12 students (65.22%). Mathematics is a subject that is rarely in demand because many students think that mathematics is difficult. Many students are less enthusiastic about attending classes because they lack motivation to learn. Students tend to be passive, afraid, and shy to ask questions. The lack of creativity of teachers in teaching and learning activities is also a factor in the lack of interest in learning among students (Agustin & Zumrotun, 2024).

Research's State of the Art

Augmented Reality (AR) is a technology that uses two-dimensional (2D) and three-dimensional (3D) virtual objects in a real-time environment. In general, AR technology is applied through two main approaches, namely marker-based AR and markerless AR. Marker-based AR utilises markers in the form of 2D illustrations resembling black-and-white squares similar to barcodes that are scanned using a smartphone camera to display 3D objects (Asrizal et al., 2024; Zhang et al., 2025). Meanwhile, markerless AR enables the appearance of 3D objects without special

markers by utilising tracking technologies, such as face tracking, 3D object tracking, motion tracking, and GPS-based tracking, thus providing greater flexibility of use (Zhang et al., 2025). Thus, AR media works through a marker scanning mechanism or direct 3D object display, making it an interactive and effective learning medium for visualising abstract concepts.

The characteristics of AR media help improve students' conceptual understanding and learning outcomes. AR can integrate the real world and the virtual world, visualise three-dimensional objects interactively, is mobile device-based, and supports independent and exploratory learning, providing positive stimuli for students on materials that require high visualisation (Pramuditya et al., 2022). One subject that requires high visualisation is solid geometry. Solid geometry is three-dimensional geometry that has length, height, and width, has volume, and has sides, angles, and vertices (Thom et al., 2024). Therefore, the use of AR media is considered relevant and effective to support solid geometry learning in a more concrete, interactive, and meaningful way.

Several studies have reported the effectiveness of using Augmented Reality (AR)-based learning media in spatial geometry material in elementary schools. Research conducted by Rukma (2025) shows that the AR-based spatial geometry learning media developed received high feasibility ratings in terms of benefits, ease of use, appearance, and clarity of material, thus making it suitable for use in learning. Another study by Mandala et al. (2025) reported that the application of AR media in the form of interactive books on spatial geometry material produced valid, practical, and effective media and was able to improve students' learning competence. Similar results were also shown by those who reported that the implementation of AR learning media in flat-sided spatial material obtained an average rating of 86.9% and was declared feasible for use in the learning process (Permatasari & Andayani, 2021).

Previous research shows that the implementation of inquiry learning in mathematics learning generally follows a systematic syntax and is oriented towards student investigation activities. The initial stage of inquiry learning begins with orientation and problem presentation, where the teacher presents phenomena or contextual problems relevant to the learning material to arouse students' curiosity and direct their attention to the concepts to be learned. The next stage is problem formulation and hypothesis, where students are encouraged to ask questions and formulate initial assumptions based on their existing knowledge. After that, students collect data through observation, exploration, or experimentation, either individually

or in groups, using available learning resources or learning media. The data obtained is then processed and analysed to identify patterns or relationships between concepts. The final stage of inquiry learning is drawing conclusions, where students formulate the results of their investigation and relate them to the mathematical concepts studied, and communicate these results through class discussions (Fadillah et al., 2026; Ismail et al., 2025; Nahar & Machado, 2025). Previous studies have reported that the application of inquiry learning in mathematics learning has a positive effect on student learning outcomes and can encourage critical thinking and problem-solving skills.

Novelty, Research Gap, & Objective

However, most previous studies have focused on product development and media quality testing in terms of validity, practicality, and media effectiveness (Flavin et al., 2025; Permatasari & Andayani, 2021; Zhang et al., 2025). Meanwhile, studies on the direct implementation of AR media in the learning process and student responses are still relatively limited (Özeren & Top, 2023; Zhang et al., 2025). These studies have not extensively examined the direct implementation of AR media in the classroom learning process, especially those that emphasise active student involvement during learning. In addition, most of these studies still discuss inquiry learning in general without specifically relating it to specific mathematics material, especially spatial geometry material in elementary school that requires high spatial visualisation skills.

Based on the state of the art described above, various studies show that Augmented Reality (AR)-based learning media are effective in improving student learning outcomes in spatial geometry, in terms of validity, practicality, and product effectiveness. On the other hand, the inquiry-based learning method has also been proven to have a positive influence on mathematics learning because it encourages students to discover concepts independently through an investigation process (Fadillah et al., 2026; Ismail et al., 2025; Jainan et al., 2025; Nahar & Machado, 2025). However, most previous studies still focus on the development and assessment of the quality of AR learning media as a product, and not many have examined the direct implementation of AR media in the learning process in the classroom. In addition, research on inquiry learning in mathematics learning in elementary schools generally does not specifically describe the integration of inquiry learning steps in a particular subject. Therefore, there is still a research gap regarding the application of AR learning media integrated with the inquiry learning method in learning spatial figures

in elementary schools, particularly in examining student responses and learning outcomes obtained through this implementation. Based on the identified research gap, this study aims to develop AR media integrated with the Inquiry Learning Model. The research question is how valid, practical, and effective Inquiry Learning-based AR Media is in teaching spatial geometry in fifth-grade elementary school.

METHOD

Type and Design

The type of research method used is *Research and Development* (R&D). This research falls under the category of educational R&D that focuses on the development of software in the form of Augmented Reality-based game media. This media focuses on mathematics subjects in spatial geometry material for fifth-grade elementary school. R&D serves to validate the resulting product so that it can be used in the learning process. Validation is carried out by considering the effectiveness, efficiency, and attractiveness of a product. The development model used is the 4D model. According to Dewy et al. (2023), the 4D model has four stages, namely *define, design, develop,* and *disseminate.* The 4D model provides a systematic and structured framework to produce high-quality products that are feasible to use and have a broad impact.

Data and Data Sources

The subjects of this study consisted of 20 fifth-grade students at Purwosari Elementary School in Wonogiri District. The class consisted of 12 female students and 8 male students. This study used two types of data sources, namely primary data and secondary data. Primary data was obtained directly through several data collection techniques, including semi-structured interviews with teachers and fifth-grade students at Purwosari Elementary School, direct observation of the learning process in the classroom, validation of Augmented Reality (AR)-based learning media by media experts, subject matter experts, and users (students), as well as learning outcome tests (pre-test and post-test). The primary data was used to obtain an authentic picture of the learning process, media feasibility, student responses, teacher responses, and the effectiveness of the developed media. Meanwhile, secondary data was obtained from various written sources relevant to the research. Secondary data included scientific journal articles, textbooks, previous research results, and other references that supported the theoretical and methodological aspects of this study.

Quantitative data on product feasibility were obtained from media experts who evaluated three aspects through 16 indicators using a Likert scale questionnaire. Subject matter experts evaluated three aspects through 18 indicators using a Likert scale questionnaire. In addition, this study also collected quantitative data on teachers' responses to the media that had been developed and implemented by evaluating 5 aspects through 15 indicators using a Likert scale questionnaire. To test the effectiveness of the product, this study used a pretest and posttest design. The design was then analysed using N-gain scores, which included multiple-choice and essay questions.

Product validation involved two media experts who are lecturers in mathematics education and elementary school teacher education. The media experts are mathematics education lecturers who have experience in research and development of technology-based media at the university level. In addition, the media experts are also elementary school teacher education lecturers who have experience in research and development of media for elementary school students. Both validators were selected based on their abilities and expertise in their fields to assess the developed media. In addition to media experts, the validation process was also carried out by subject matter experts who are certified elementary school teachers.

Data Collection Technique

Data collection in this study was carried out at Purwosari State Elementary School by involving elementary school teachers and students as research subjects. Various instruments were used to obtain comprehensive data related to the feasibility, practicality, and effectiveness of Augmented Reality (AR)-based learning media using the Augmented Inquiry approach in spatial geometry material. Product validation was carried out by media experts and subject matter experts using a Likert scale-based questionnaire instrument. Validation by media experts focused on the aspects of visual design, interactivity, ease of use, and technical performance of AR media, while validation by subject matter experts emphasised conceptual accuracy, material suitability with the curriculum, clarity of presentation, and integration of inquiry learning principles in spatial geometry material.

In addition, a teacher response questionnaire was used to collect data on the practicality of using the media and its suitability for the learning process in the classroom. A student response questionnaire was used to determine the level of acceptance, engagement, and learning experience of students after using AR-based learning media. To measure the effectiveness of the media, a learning outcome test in

the form of a pretest and posttest was used. The pretest was given before the implementation of the media to determine the initial abilities of the students, while the posttest was given after the use of the media in learning. The test result data were then statistically analysed to determine the significance of the increase in learning outcomes as a result of using the developed learning media.

Data Analysis

Data analysis in this study used qualitative and quantitative approaches. Quantitative analysis was performed on the data from the validation of media experts and subject matter experts obtained through a five-point Likert scale questionnaire instrument. The assessment scores were analysed by calculating the percentage to determine the feasibility level of augmented reality (AR)-based learning media. The feasibility level of the media was based on aspects of media design, content quality, ease of use, and comprehensibility of the material. A qualitative descriptive approach was used to interpret non-numerical data obtained from the validation results and user responses to the developed augmented reality (AR)-based learning media. The assessment results from each expert were compiled and grouped based on the aspects assessed, including media design, content quality, ease of use, and comprehensibility of the material. Furthermore, the scores obtained were calculated in the form of percentages to determine the overall feasibility level of the learning media. Data interpretation was carried out descriptively to identify the strengths and limitations of the developed media.

Data analysis techniques were obtained from assessment or validation scores from media experts and subject matter experts, with the following conditions: (See Table 1)

Table 1. Validation Scores

Category	Score
Very Good	5
Good	4
Fairly good	3
Not good	2
Very poor	1

Based on the scores obtained from media experts 1 and 2 above, the scores can be processed as follows:

$$\text{Suitability (\%)} = \frac{scores\ obtained}{Maximal\ Skor} \text{x } 100\%$$

The media feasibility rating is calculated based on the scores given by media experts and subject matter experts using the following criteria: (See Table 2)

Table 2. Media Validity and Practicality Categories

Percentage	Validity Criteria	Practicality Criteria
84-100	Highly Feasible	Very Practical
68-83	Suitable	Practical
52-67	Fairly Acceptable	Fairly Practical
36-51	Less Acceptable	Less Practical
20-35	Not Suitable	Not Practical

Improvements in both types of exams were analysed using the N-gain formula

$$N - gain = \frac{Post\ test\ score - Pre\ test\ score}{Maximum\ score - Pre\ test\ score}$$

N-gain scores were categorised as high (N-gain ≥ 0.7), moderate (0.3 ≤ N-gain < 0.7), or low (N-gain < 0.3). The product is declared effective if the N-gain for both tests is at least moderate (≥ 0.3), and interest in spatial construction material increases with at least 80% of students reaching the 'High' category (≥ 6).

RESULT

The learning media developed is Augmented Reality (AR) learning media for fifth-grade elementary school students with an inquiry learning model on spatial geometry material. The AR learning media is delivered as an application that offers flexibility in use and operation. The AR learning media was created with several supporting programs, such as Canva, CapCut, and Unity. This AR learning media was compiled following the inquiry learning model, namely, problem orientation, problem gathering, hypothesis gathering, material gathering, hypothesis testing, and conclusion. This AR learning media contains spatial geometry mathematics material that focuses on the properties of cubes, blocks, pyramids, prisms, and cylinders.

This learning media has been tested by media experts and subject matter experts. The first media expert is a lecturer in Elementary School Teacher Education at Muhammadiyah University Surakarta. The second media expert is a lecturer in Mathematics Education. In addition, this study used subject matter experts, namely two teachers from Purwosari Elementary School. The product that has been assessed by experts is then revised. The product is revised based on the comments and input from the experts during the study. The experts' input and suggestions were then considered and developed as a reference for refining the product.

Results of Media Expert Validation

The learning media validation was carried out by a media expert who has competence in the field of instructional design and educational technology. The validation process aims to evaluate the visual aspects, functionality, usability, and pedagogical suitability of the augmented reality-based media developed. The media validation results can be seen in Table 4 below.

Table 3. Results of Expert Validation for Materials 1 and 2

Evaluation Aspects	Total Media Expert 1	Total Media Expert 2	Maximum Score	Percentage
Media Display Design	34	34	40	85%
Software	22	20	25	84%
Benefit Aspect	13	11	15	80%
Total Score Obtained	**134**			
Maximum Total Score	**160**			
Score Percentage	**84%**			
Category	**Highly Feasible**			

Based on Table 3, the validation results from two media experts showed that the AR learning media that had been developed was declared "very feasible" with a total percentage of 84%. The assessment was carried out on three main aspects, including media display design, software, and benefits. In terms of media display design, the score was 34 from media expert 1 and 40 from media expert 2, with a maximum score of 40. The assessment percentage for this aspect was 85.00%, indicating that the media was appropriate based on eight indicators of media display design achievement. The indicators of achievement for media display design include the suitability of the media for competency achievement, an attractive media display design with the right color selection, easy-to-read text in the application, easy navigation buttons for accessing the application content, clear button display and appropriate colors, appropriate and neat layout of components in the application, clear 3D images, and clear instructions for using the application.

In terms of software design, it received a score of 22 from media expert 1 and 20 from media expert 2, with a maximum score of 25. The assessment percentage for this aspect was 84.00%, indicating that the media was appropriate based on the 5 indicators of software design achievement. The indicators of achievement based on software design include the camera being able to display 3D images in a short time, the media being able to be used without bugs, crashes, or lag, the navigation buttons being easily accessible from scene to scene, the AR learning media being communicative, and the AR learning media being interactive.

In terms of benefits, it scored 13 from media expert 1 and 11 from media expert 2, with a maximum score of 15. The percentage of assessment in this aspect was 80.00%, indicating that the media was appropriate based on 3 indicators of achievement in terms of benefits. These achievement indicators include: the media provides new knowledge about AR technology, AR learning media increases students' interest and enthusiasm for learning, and AR learning media makes it easier for teachers to deliver spatial geometry material directly.

Results of Content Expert Validation

Expert material validation was obtained from the questionnaire scores filled out by the material experts. The scores obtained by the material experts are attached in Table 4 as follows:

Table 4. Validation Results from 2 subject matter experts

Evaluation Aspect	Total Media Expert 1	Total Media Expert 2	Maximum Score	Percentage
Learning Design	18	16	20	85.00
Material Aspects	46	42	50	88.00
Benefit Aspects	19	18	20	92.50%
Total Score Obtained	**159**			
Maximum Total Score	**180**			
Score Percentage	**88.33%**			
Category	**Highly Feasible**			

Based on Table 4, the validation results from two subject matter experts show that the AR learning media that has been developed is declared "highly feasible" with a total percentage of 88.33%. The assessment was carried out on three main aspects, including learning design, material aspects, and benefit aspects. In the learning design aspect, it received a score of 18 from subject matter expert 1 and 16 from subject matter expert 2, with a maximum score of 20. The assessment percentage for this aspect was 85.00%, indicating that the media was appropriate based on four indicators of media display design achievement. The indicators of media display design achievement included the relevance of the material to the learning outcomes, the attractiveness of the material presented, ease of understanding, and clarity of language use.

In terms of material, it received a score of 46 from material expert 1 and 42 from material expert 2, with a maximum score of 50. The percentage of assessment in this aspect was 88.00%, indicating that the media was appropriate based on 10 indicators of achievement in terms of benefits. The indicators of achievement of the benefit aspect include well-presented material, discussion and examples of material,

material in the media that is well adapted, clear instructions for completion, clearly formulated questions in the material, questions that are correct according to theory and concept, questions covered in the media, an appropriate level of difficulty for the questions, the suitability of AR to the material, and images in the media that are appropriate to the material.

In terms of benefits, it scored 19 from subject matter expert 1 and 18 from subject matter expert 2, with a maximum score of 20. The assessment percentage for this aspect was 92.50%, indicating that the media was appropriate based on 4 indicators of achievement in terms of benefits. Indicators of achievement in the benefit aspect include the media providing new knowledge about AR technology, the benefit of increasing insight, which AR learning media can overcome the limitations of teaching aids, and the media makes it easier for teachers to deliver material.

Teacher Assessment Results

The teacher assessment results were obtained from the questionnaire scores filled out by fifth-grade teachers as their response to the learning process. The scores obtained by the subject matter experts are attached in Table 6 as follows:

Table 5. Learning Assessment Results from 2 Teachers

Assessment Aspect	Total Teacher Assessment 1	Total Assessment of Teacher 2	Maximum Score	Percentage
Effectiveness	19	16	20	87.5%
Relevance	13	13	15	86.7%
Efficient	8	9	10	85.0%
Usefulness	18	16	20	85.0%
Contextual	8	9	10	85.0
Total Score Obtained	**149**			
Maximum Total Score	**170**			
Score Percentage	**87.6%**			
Category	**Very Practical**			

Based on Table 5, the assessment results from the two teachers showed that the learning that had been carried out was declared "very feasible" with a total percentage of 87.6%. The assessment was carried out on five main aspects, including effectiveness, relevance, efficiency, usefulness, and contextuality. In terms of effectiveness, Teacher 1 gave a score of 19 and Teacher 2 gave a score of 16, with a maximum score of 20. The assessment percentage for effectiveness was 87.5%, indicating that the learning was appropriate based on the four indicators of effectiveness achievement. The indicators of achievement for the effectiveness aspect

included the sequence of trial activities in accordance with the inquiry syntax, illustrations/images in accordance with the material, clear activities, and clear 3D image display.

In terms of relevance, the score was 13 from teacher 1 and 13 from teacher 2, with a maximum score of 15. The percentage of assessment in terms of relevance was 86.7%, indicating that the learning was appropriate based on 3 indicators of relevance. The indicators of achievement for the relevance aspect include appropriate material in the media, questions presented in accordance with the material, and questions presented that support learning development.

In terms of efficiency, Teacher 1 scored 8 and Teacher 2 scored 9 out of a maximum score of 10. The percentage of assessment in terms of effectiveness was 85.00%, indicating that the learning was appropriate based on two indicators of achievement in terms of efficiency. The indicators of achievement in terms of efficiency included the need for learning support equipment and learning activities in accordance with the time allocation.

In terms of usefulness, it scored 18 from teacher 1 and 16 from teacher 2, with a maximum score of 20. The percentage of assessment in terms of usefulness was 85.00%, indicating that the learning was appropriate based on 4 indicators of achievement in terms of usefulness. Indicators of the usefulness aspect include students being interested in participating in learning, learning activities increasing students' thinking skills, media helping students to learn independently, and the developed material being easy to understand.

In the contextual aspect, the score was 8 from teacher 1 and 9 from teacher 2, with a maximum score of 10. The percentage of assessment in the contextual aspect was 85.00%, indicating that the learning was appropriate based on 2 indicators of achievement in the contextual aspect. Indicators of the contextual aspect include language that is easy to understand and media that have an attractive appearance.

Student Assessment Results

Student assessment was conducted by all fifth-grade students at Purwosari Elementary School. The results of the student assessment were used to test the suitability of the media. See Table 9 for the results of the student assessment.

Table 6. Student Response Questionnaire Results

Indicator	Indicator Description	Total Score	Average Score	Percentage
Q1	Attractive learning media display	81	4.05	81

Q2	Colours and images in the media are clear and appropriate	76	3.8	76
Q3	The text and letters on the media are easy to read.	84	4.2	84
Q4	Learning media is easy to use	69	3.45	69
Q5	Instructions for using the media are easy to understand	86	4.3	86
Q6	The material in the media is easy to understand	60	3	60
Q7	Examples/illustrations in the media aid comprehension	84	4.2	84
Q8	Learning media attracts interest in learning	61	3.05	61
Q9	Learning media increases learning motivation	87	4.35	87
Q10	Media is useful in the learning process	68	3.4	68
Number		756	37.8	756%
Average		37.8	1.89	3.78
Average Percentage		(3.78 / 5) × 100% = 75.60%		
Product Practicality Category		**Practical**		

Based on Table 6, the results of the student response questionnaire regarding the use of Augmented Reality (AR) learning media in fifth-grade spatial geometry material show a very positive response. The average percentage obtained was 75.60%, with an overall average score of 3.78, so that the media developed falls into the practical category. This shows that AR learning media is easy to use and well accepted by students in the learning process.

In detail, the indicator with the highest percentage is learning media that increases learning motivation (Q9) with a percentage of 87%, followed by easy-to-understand media usage instructions (Q5) at 86%, as well as attractive learning media displays (Q1) and examples/illustrations that aid understanding (Q7), each reaching 84%. These findings indicate that AR media is able to attract students' attention, provide an enjoyable learning experience, and help them understand spatial concepts.

Meanwhile, several indicators obtained lower percentages, such as learning media that attracts interest in learning (Q8) at 61% and material in media that is easy to understand (Q6) at 60%. However, these results still show that AR learning media generally provide benefits and convenience for students in the process of learning spatial geometry.

Results of the Media Effectiveness Trial

This trial was conducted to determine the effectiveness of the media in improving student learning outcomes. This was done by giving a pre-test assessment before conducting learning using learning media, and giving a post-test assessment after conducting learning using learning media.

Table 7. Dependent T-test for Pre-Test and Post-Test Data

Variable	N	Mean	Mean Difference	Calculated t	df	Sig. (2-tailed)	Description
Pretest	20	66.00					
Posttest	20	82.75	-16.75	-7.02	19	0.000	Significant

Based on Table 7, the results *of the* paired *t-test* show that the significance value (Sig. 2-tailed) is 0.000, which is smaller than 0.05, with a t-value of −7.019. This indicates that there is a significant difference between the pretest and posttest scores of students after learning using Augmented Reality (AR) media on spatial figures in grade V.

Descriptively, the average student score on the pretest was 66.00, while the average posttest score increased to 82.75 after learning using AR media was applied. This increase in the average score shows that the use of AR media can help students visualise spatial shape concepts more concretely and interactively, making it easier for students to understand the shapes, properties, and elements of spatial shapes. Thus, it can be concluded that learning using AR media has a positive and significant effect on the mathematics learning outcomes of fifth-grade students on spatial shape material.

Table 8. N-Gain Pretest and Posttest of Learning Outcomes

Number of Students	Average Pretest	Maximum Pretest Score	Average Posttest	Maximum Posttest Score	N-Gain	Category
20	66.00	100	82.75	100	0.46	Moderate

Based on the results of the N-Gain analysis, an average score of 0.46 was obtained, which falls into the moderate category. This shows that the learning methods applied were quite effective in improving student learning outcomes, although the improvements varied among students.

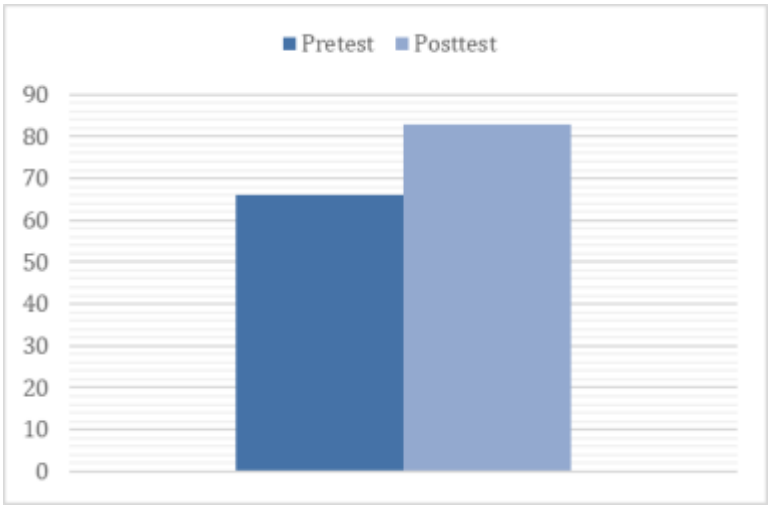

Figure 1. Graph illustrating the average scores of students' knowledge test

The graph shows a comparison of the average pretest and posttest scores of students' knowledge. Based on the graph, the average pretest score of students is 66, while the average posttest score increases to 82.75. This increase shows a difference of 16.75 points after students participated in the learning process. These results indicate that the learning provided was able to significantly improve students' knowledge. Thus, it can be concluded that the treatment or learning media applied is effective in improving student learning outcomes.

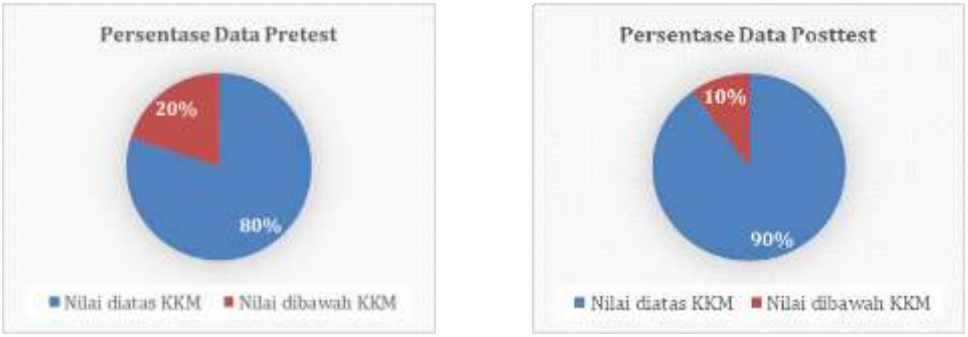

Figure 2. Graph of the Percentage of Students' Knowledge Test Mastery

Based on the pre-test results, out of 20 students, 16 students (80%) obtained scores above the minimum passing score, while 4 students (20%) obtained scores equal to or below the minimum passing score. These results indicate that most students had not achieved learning mastery at the pre-test stage. The low scores indicate that the students' initial understanding of solid geometry material was still limited. Therefore, it is necessary to apply more innovative learning media or strategies to improve student learning outcomes.

Based on the post-test chart of 20 students, there were 2 students (10%) who scored below the minimum passing grade, while 18 students (90%) scored at or

above the minimum passing grade. These results indicate that most students have achieved learning mastery. The dominance of scores above the minimum passing score indicates an improvement in student learning outcomes after participating in the learning process. Thus, the learning process that was implemented can be said to be effective in helping students achieve the expected competencies.

Product Revision

Based on the comments and suggestions provided by media experts, the product was revised in accordance with the input and suggestions from the validators. The suggestions and revisions are explained in Table 10 as follows.

Table 10. Product Revision

Comments and Suggestions	Revisions
The font color of the title blends in with the background; it can be changed and adjusted.	Change the font color and background of the media title.
Lack of prompting questions in the "Problem Orientation" menu.	Add prompting questions to the Problem Orientation menu.
In the "Let's Find Out" menu, add a highlight to the build room button	Add a highlight to the build space button.

The media display before and after revision, the first one changes the font colour and background colour of the media title. Figure 3 shows the menu before and after revision in the application.

Figure 3. Media Title Design Revision

The second revision is adding a prompt question to the Problem Orientation menu. Figure 4 shows the results of the improvements to the problem orientation menu before and after revision as follows.

Figure 4. Revision of the Problem Orientation Menu

The third revision is to add a highlight to the build room button. Figure 5 shows the results of the improvements to the build room button menu before and after revision as follows.

Figure 5. Revision of the Build Space Button

DISCUSSIONS

This study aims to develop AR learning media for fifth-grade solid geometry material in elementary school using the inquiry learning model. The integration of augmented reality (AR) in inquiry-based learning models significantly improves the educational experience, especially in subjects such as mathematics and science (Akbar et al., 2025; Anna & Spyros, 2025). Inquiry learning encourages active engagement, allowing students to manipulate virtual objects and explore complex concepts in a more interactive way. The use of AR technology in learning can enhance the learning experience to be more interesting, interactive, and meaningful (Putri et al., 2024; Nurza et al., 2021). Additionally, AR media can help students understand abstract concepts through the visualization of three-dimensional objects. The media development process follows the 4D model (define, design, develop, disseminate). However, at the design stage, obstacles were encountered in the form of a lengthy application coding process and design adjustments to align with the inquiry learning syntax. These obstacles indicate that technology-based media development requires careful technical and pedagogical planning so that the resulting product remains in line with the learning objectives.

Practicality and Effectiveness Product Validity

In terms of product validity, the assessment results from media experts and subject matter experts indicate that the developed AR learning media is highly feasible. The media expert validation confirms that the visual display, navigation, and functionality of the application are in line with the characteristics of elementary school students and are able to optimally support the visualisation of spatial material. Meanwhile, content expert validation indicates that the learning content aligns with learning outcomes, the applicable curriculum, and is presented in an easily understandable language. The absence of substantial revisions to the content aspect indicates that the integration between solid geometry content and the inquiry learning model has been systematically designed and meets pedagogical standards. These findings are in line with previous studies stating that AR media that are technically and pedagogically valid can improve students' understanding of geometry concepts (Flavin et al., 2025; Özeren & Top, 2023).

In terms of product practicality, the results of teacher assessments and student responses indicate that AR learning media are easy to use, relevant to the material, time-efficient, and contextual to classroom learning needs. Teachers assessed that the media could assist the learning process and facilitate active student engagement in

accordance with the inquiry learning stages. Student responses also showed a good level of acceptance of the media, particularly in terms of appearance, ease of use, and clarity of instructions. This indicates that the media is not only theoretically feasible but also practical for implementation in real learning situations. These findings are in line with the opinions of Lee et al. (2021), who stated that application-based learning media need to fulfil the aspects of ease of use, ease of recall, low error rates, and user satisfaction.

In terms of product effectiveness, the trial results showed an increase in student learning outcomes after using AR learning media based on inquiry learning. The increase in pre-test to post-test scores and N-Gain values in the moderate category indicates that the media is quite effective in improving students' understanding of spatial geometry material. In addition, learning with AR media can increase student enthusiasm, as shown through active involvement in discussions, media exploration, and completing tasks independently or in groups. These findings are in line with the research by Sulianto et al. (2025), which states that innovative AR-based learning media can increase students' interest and learning outcomes. Thus, the application of inquiry learning-based AR learning media not only improves the cognitive learning outcomes of students but also encourages active involvement and learning motivation among students in the learning process.

The Learning Process with AR Media Using the Inquiry Learning Model

Mathematics learning in spatial geometry requires students' ability to understand abstract and visual-spatial concepts. This often causes difficulties in visualising three-dimensional shapes, recognising spatial geometry elements, and understanding the relationships between elements (Mathias et al., 2024; Thom et al., 2024). The use of Augmented Reality (AR)-based learning media is a relevant solution because it allows solid objects to be displayed in three-dimensional visual forms that can be rotated, enlarged, and observed from various angles, thereby helping students understand spatial geometry concepts more concretely. In this study, AR media was applied using the Inquiry Learning model, which emphasises the active involvement of students in discovering knowledge through the investigation process. This model is in line with the characteristics of AR because both encourage students to observe, ask questions by formulating hypotheses, explore by collecting data and testing hypotheses, and conclude based on the learning experiences gained.

Figure 6. Learning Process of Observing

Figure 7. Learning Process of Formulating Hypotheses

Figure 8. Learning Process of Exploring

Figure 9. Learning Process: Drawing Conclusions

Figure 6 shows students observing spatial objects through AR media on smartphones while matching them with worksheets. This activity is in line with the orientation and problem formulation syntax, where teachers direct students to observe real geometric phenomena through 3D displays so that students can formulate the focus of the learning problem. Research shows that the use of AR media in geometry helps visualise three-dimensional shapes so that students can more easily observe and understand the relationships between spatial elements in a concrete and interesting way compared to conventional media (Mandala et al., 2025; Nadzeri et al., 2024).

Figure 7 shows students discussing in groups to discuss their initial assumptions about the properties of spatial figures based on what they see from AR media. This is where students formulate hypotheses, namely expressing predictions related to the number of sides, edges, or vertices of the observed spatial figures. The

findings of Thom et al. (2024) state that AR supports students' spatial reasoning abilities in geometry because students can rotate and manipulate objects interactively, so that hypotheses can be constructed from real experiences with these objects.

Figure 8 shows students directly exploring AR media to enlarge or rotate solid objects. This activity is in line with the syntax of collecting data, where students explore to obtain information that supports or refutes their hypotheses (Lee et al., 2021). The research article states that exploratory activities such as rotating and enlarging AR objects are effective in improving students' visual-spatial abilities because they gain concrete experience in exploring the abstract properties of 3D shapes in geometry.

In Figure 9, students are presenting their findings or discussion results in front of the class. This is in line with the drawing conclusions syntax, where students conclude the results of their investigation based on the data obtained. AR media helps clarify the concepts that have been explored because 3D visual representations make it easier for students to compare their ideas with the actual facts of the object. Research has found that AR media can strengthen students' understanding of spatial concepts and spatial reasoning abilities, so that the conclusions drawn are more meaningful and in line with the abstract reality being studied. This is in line with the findings of Anna & Spyros (2025), who state that conclusions drawn based on students' independent reasoning are more meaningful and contextual.

Student Responses to the Developed Media

Indicators Q1, Q2, and Q3 show high percentages, 81%, 76%, and 84%, respectively. This indicates that the media display, colour, and image suitability, and text readability meet the needs of students. Attractive visual displays play an important role in increasing student comfort and focus in learning. These findings are in line with research by Hariyono et al. (2023), which states that attractive and proportional visual designs of learning media can increase students' interest in learning and their positive perceptions of digital learning media.

On indicators Q4 and Q5, the media obtained percentages of 69% and 86%. Although the ease of use indicator is still in the practical category, the lower value in Q4 indicates that some students still need to adapt to using the media. However, the high percentage on the usage instructions indicator indicates that the instructions provided are sufficient to help students operate the media. This is supported by research by Procopio et al. (2024), which states that the clarity of usage instructions

is a major factor in improving the practicality of technology-based learning media, especially for elementary and middle school students.

Indicators Q6 and Q7 show varying results, namely 60% for ease of understanding the material and 84% for illustrative examples. The low score on Q6 ( ) indicates that although the illustrations are helpful, the presentation of the material still needs to be simplified or adapted to the characteristics of the students.

Indicators Q8 and Q9 obtained percentages of 61% and 87%. These results indicate that the media is more effective in increasing learning motivation than students' initial interest in learning. Interactive and visual media can encourage students to be more motivated to participate in learning. These results are in line with the research by Sari et al. (2025), which states that interactive technology-based learning media, including Augmented Reality, have a significant effect on increasing student learning motivation. Indicator Q10 shows a percentage of 68%, which indicates that the media is considered quite useful in the learning process. Overall, learning media can support the learning process, although there are still several aspects that need to be improved, particularly in terms of simplifying the material and ease of use.

CONCLUSION

This study produced Augmented Reality (AR) learning media on fifth-grade elementary school spatial geometry material developed using the Inquiry Learning model. The validation results by media experts and subject matter experts showed that AR learning media were very suitable for use in mathematics learning. Teachers' assessments also showed that learning using AR media was very practical, while students' responses showed that it was practical, indicating that the media was easy to use, interesting, and useful in the learning process. The effectiveness test shows that the use of AR learning media has a significant effect on improving student learning outcomes, as indicated by the difference in pretest and posttest scores with a significance value of < 0.05. In addition, the N-Gain value of 0.46 is in the moderate category, which indicates that the AR learning media is quite effective in improving the understanding of solid geometry concepts. Thus, Inquiry Learning-based AR learning media can be used as an alternative, innovative learning media to support mathematics learning in elementary schools. The development of this media is still limited to AR-based spatial geometry material for fifth-grade elementary school students. Further studies are recommended to expand the scope of AR-based learning

materials to other topics and to test their effectiveness in various levels of education and broader learning contexts. Based on the research conducted, the following suggestions and recommendations for development are provided: 1) This media can only be operated on Android-based devices with a minimum operating system version of 8.0 (Oreo). Devices with lower versions experience application instability or cannot run AR features optimally. This limits the media's accessibility to users with low-spec devices. 2) The application requires devices that support AR technology, specifically those compatible with ARCore (Google's AR framework). Not all Android devices are equipped with sensors and cameras that support this feature, so only certain devices can be used to access the full learning content.

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