

THE DEVELOPMENT OF AUGMENTED REALITY-BASED LEARNING TO IMPROVE STUDENTS' MATHEMATICAL COMMUNICATION SKILLS AND SELF-EFFICACY

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ABSTRACT

This study aims to develop Ruang GIRA (Geometry Interactive Reality Augmented), an Augmented Reality (AR)-based learning medium for polyhedra at the junior high school level, and to examine its feasibility and effectiveness in improving students' mathematical communication skills and self-efficacy through the Discovery Learning model. The study was prompted by students' difficulties in visualising three-dimensional objects, which result in poor communication skills and reduced confidence when solving geometry problems. Ruang GIRA addresses this issue by providing an immersive learning experience that allows students to interact with virtual geometric objects, thereby bridging the gap between abstract concepts and visual representation. The research employed a Research and Development (R&D) method based on the ADDIE model, consisting of the following stages: Analysis, Design, Development, Implementation, and Evaluation. The subjects were Year 9 students. The media's feasibility was validated by material and media experts, indicating its high feasibility. Students responded very positively, giving an average score of 3.43 out of 4, and the media's effectiveness was demonstrated by an N-Gain score of 0.68, categorised as moderate, indicating improvement in mathematical communication skills. Additionally, self-efficacy increased more significantly among students in the experimental class than in the control class. These findings suggest that Ruang GIRA is a feasible and effective innovative learning medium for teaching polyhedra. It supports students' conceptual understanding while enhancing communication skills and self-efficacy. Future research should focus on improving its features by integrating surface area and volume calculations and expanding its implementation to broader contexts and different educational levels.

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INTRODUCTION

Mathematics has a strategic role in shaping logical, analytical, and systematic thinking skills, and serves as a means for developing reasoning and communication in various life contexts

(Kilpatrick et al., 2001; Turan et al., 2025). At the primary and secondary education levels, mathematics learning becomes an important foundation for mastering twenty-first-century competencies, including critical thinking, data literacy, and complex problem solving (Badjeber & Purwaningrum, 2018; Pellegrino & Hilton, 2012). Therefore, the quality of mathematics learning is determined not only by procedural mastery, but also by students' ability to communicate mathematical ideas coherently and to build self-confidence in the learning process.

However, mathematics learning in schools continues to face various challenges. Learning practices that are oriented toward final outcomes and dominated by one-way instructional methods often limit students' opportunities to explore concepts and construct meaningful understanding. This condition affects the low quality of mathematical interaction in the classroom and the weak mathematical communication skills of students (OECD, 2019). These limitations are reflected in students' difficulties in expressing mathematical ideas both orally and in written form, constructing logical arguments, and translating real-world problems into appropriate mathematical representations. In addition, students often struggle to interpret symbols, diagrams, and graphs meaningfully. Empirical findings indicate that students tend to lack confidence in expressing mathematical ideas and experience difficulties in explaining their reasoning in written and visual forms (Putri et al., 2018). Furthermore, low self-confidence, limited interest, and negative perceptions of mathematics as a difficult and intimidating subject further hinder the development of students' mathematical communication skills (Putri et al., 2018). These problems are exacerbated by limited opportunities for discussion-based learning, the dominance of teacher-centred instructional practices, and students' low self-efficacy in communicating their reasoning. In fact, mathematical communication is an essential competency that supports argumentation, representation, and conceptual understanding, and has become one of the key focuses of reinforcement in the Merdeka Curriculum (Kemendikbudristek, 2022; NCTM, 2000).

In addition to cognitive aspects, affective factors, particularly self-efficacy, also play an important role in the success of mathematics learning. Self-efficacy influences the choice of learning strategies, students' persistence, and their resilience in facing difficulties (Bandura, 1997). Various studies indicate that low mathematical self-efficacy causes students to be reluctant to express opinions, easily give up, and lack confidence in solving problems, especially in topics that require high levels of conceptual understanding and visualization, such as geometry (Hendriana & Kadarisma, 2019). One of the topics that frequently causes difficulties is polyhedra, which require spatial visualization skills and an understanding of the relationships among three-dimensional elements (Fujita et al., 2020; Van Hiele, 1986). As reported by Anggo et al. (2022); Simamora et al. (2024); Wulandari (2019) In learning practice, ninth-grade students often have difficulty visualizing the shapes of three-dimensional figures concretely and imagining the transformation of three-dimensional models into their net forms. These visual-spatial difficulties result in low conceptual understanding and weak mathematical representation skills among students, which ultimately affect their inability to solve problems related to spatial orientation and the construction of geometric forms (Putra et al., 2022; Sinuraya et al., 2024). Thus, learning approaches and media are needed that can present geometric objects in a more concrete, interactive, and easily understood manner in accordance with students' cognitive developmental needs (Yuliani et al., 2024).

Conventionally, teachers use two-dimensional learning media based on images in textbooks or on the blackboard, as well as simple, concrete models with limited variety. Such media provide only static representations and are therefore unable to display dynamic shape changes, such as rotations or the transformation of nets into complete three-dimensional solids. This condition limits students' learning experiences, preventing them from exploring the structure of three-

dimensional figures in depth and independently (Sinaga et al., 2025). On the other hand, current developments in educational technology provide opportunities to present geometric visualizations that are more realistic, interactive, and easily accessible through digital devices. Learning approaches based on interactive digital media allow students to manipulate geometric objects directly, construct understanding through exploratory practice, and increase engagement in learning (Aldin et al., 2024). Therefore, the use of technology that integrates three-dimensional visualization with user interaction is important for overcoming the limitations of conventional media and strengthening students' understanding of spatial concepts. One technology that can be integrated into learning is Augmented Reality (AR), which combines virtual objects with the real environment in real time, allowing users to view and manipulate three-dimensional representations more clearly (Azuma, 1997). AR not only provides more concrete visualizations but also enables students to interact directly with geometric objects by rotating, enlarging, reducing, and observing them from various perspectives (Nindiasari et al., 2024). In mathematics education, this technology can facilitate a more meaningful understanding of abstract concepts through exploration-based learning experiences. Various studies have shown that the use of AR can increase student engagement, learning motivation, as well as visual representation skills and spatial reasoning abilities (Sudirman et al., 2024; Victor et al., 2024). In addition, according to Sungkono et al. (2022), AR is considered effective in supporting independent and collaborative learning because it provides interactive media that are responsive to user activities. Thus, AR becomes a relevant and potential alternative learning medium to overcome students' difficulties in understanding polyhedra in a more concrete and structured manner. In addition, several studies have reported that AR-based learning media can enhance motivation and understanding of geometric concepts and enrich students' interactions with mathematical objects (Bulut & Ferri, 2023; Dunleavy & Dede, 2014). Among available approaches, AR is considered one of the most effective means of overcoming the limitations of conventional media in facilitating spatial visualization.

However, previous studies have generally focused on media feasibility or improvements in cognitive learning outcomes. Studies linking the use of AR to the strengthening of students' mathematical communication skills and self-efficacy remain limited, particularly at the junior high school level and in the context of polyhedra. In addition, some studies have not systematically developed AR media using a structured development model such as ADDIE, resulting in incomplete documentation of media development and evaluation processes. On the other hand, the implementation of the Discovery Learning model has been proven effective in encouraging student activeness and reflective thinking processes (Bruner, 1961). However, it has still rarely been examined in the context of utilizing AR media as a supporting tool for classroom learning. Given these limitations, this study is expected to contribute by systematically developing AR-based learning media using the ADDIE model and by examining their use in mathematics learning that applies the Discovery Learning model during classroom implementation. The uniqueness and scientific value of this study lie in its simultaneous focus on the development of AR-based learning media and on the examination of their impact on junior high school students' mathematical communication skills and self-efficacy, which have been examined relatively rarely together in previous studies.

Based on observations conducted at a junior high school in Cianjur Regency, students continued to experience difficulty in understanding and accurately identifying the shapes and structures of polyhedra. These difficulties were particularly evident when students were asked to determine the relationships among the elements of three-dimensional figures or to relate them to net representations. Further analysis of the learning media used to date revealed that conventional media, such as two-dimensional images in textbooks and limited physical models, are insufficient for presenting dynamic, interactive three-dimensional object visualizations.

These media are considered less capable of providing students with direct manipulative experiences to explore transformations between three-dimensional forms and two-dimensional nets, thereby hindering the development of comprehensive spatial understanding (Aulia et al., 2023; Mandala et al., 2025). To overcome the limitations of existing media while simultaneously addressing students' learning difficulties, AR-based learning media were developed to provide more realistic, interactive, and immersive learning experiences.

Based on these various problems, it is necessary to develop learning media that are not only visual in nature but also capable of supporting students' conceptual understanding and facilitating active engagement in the mathematics learning process. Therefore, this study develops an Augmented Reality-based learning media designed to present interactive three-dimensional visualizations to help students understand the concepts of polyhedra more concretely. This media integrates visual representations, learning contexts, and mathematical symbolism, enabling students to express and communicate mathematical ideas more clearly while strengthening their confidence in learning mathematics.

Accordingly, this article aims to examine how the development of Augmented Reality-based learning media can function as an effective tool for improving junior high school students' mathematical communication skills and self-efficacy, as well as contribute to the advancement of technological innovation in mathematics education.

METHOD

This study employed a Research and Development (R&D) method to develop and evaluate an Augmented Reality (AR)-based learning media, Ruang GIRA, for improving students' mathematical communication skills and self-efficacy. The ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) was adopted due to its systematic and flexible framework for developing technology-based instructional media (Branch, 2009). The following figure presents the development of the learning media using the ADDIE model:

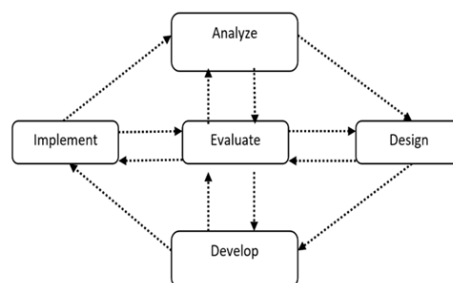


Figure 1. ADDIE Model Development Framework (Slamet, 2022)

In the Analysis stage, students' needs, characteristics of polyhedra material, and school facilities were identified. The Design stage involved developing the application interface, interaction flow, and three-dimensional content. In the Development stage, the AR media was created, validated by material and media experts, and tested through a limited trial. The Implementation stage involved classroom learning using the Discovery Learning model supported by AR media, while the Evaluation stage was conducted both formatively and summatively to assess media quality and effectiveness.

Data were collected through questionnaires, interviews, observations, and tests. Questionnaires were used to assess media quality by media experts (technical and visual aspects), subject matter experts (content suitability), and students (instructional aspects and ease of use). Data were analyzed descriptively using a semantic differential scale and percentage calculations to determine product feasibility (Hendryadi, 2017). Interface evaluation referred to the Questionnaire for User Interface Satisfaction (Perlman, 1998), while content and learning

objectives were assessed based on criteria by (Walker & Hess, 1984). Data analysis followed the stages of data reduction, data presentation, and conclusion drawing (Sugiyono, 2018).

To examine effectiveness, a quasi-experimental non-equivalent control group design was employed, as random assignment was not feasible in school settings (Creswell & Creswell, 2017). The experimental class used AR-based Ruang Gira media with the Discovery Learning model, while the control class used Discovery Learning without AR. Both groups were given a pretest and posttest to measure learning improvement (Sugiyono, 2019), with the design referring by Ruseffendi (2010) as follows:

O	X	O
O	—	O

Description:

O : Pretest – Posttest

X : Treatment in the form of the use of AR media

Data were analyzed descriptively and effectiveness was examined using N-Gain analysis. Statistical analysis was conducted using SPSS, employing the independent sample t-test or Mann–Whitney test based on data distribution. The formula of N-Gain according to Hake (1999) is as follows:

$$N - gain = \frac{Postes - Pretes}{SMI - Pretes}$$

The criteria for N-Gain levels are presented in the following table:

Gain Value	N-Gain Level
$g \geq 0,7$	High
$0,3 \leq g < 0,7$	Moderate
$g < 0,3$	Low

In addition to the mathematical communication skills test, the researchers developed a Self-Efficacy scale to measure indicators of confidence in one's abilities, confidence in one's success, persistence in completing difficult tasks, courage to face challenges, and the ability to interact with others. The instrument consisted of 32 statements, comprising 19 positive statements and 13 negative statements.

The population of this study comprised all ninth-grade students at a junior high school in The population consisted of ninth-grade students in a junior high school in Cianjur Regency. The sample was selected purposively and divided into a limited trial (10 students) and a main trial involving two classes of 29 students each. The results were used to evaluate the feasibility and effectiveness of the developed media in enhancing students' mathematical communication skills and self-efficacy.

RESULTS AND DISCUSSION

Results

The Augmented Reality-based learning media developed in this study is named "Ruang GIRA." The term Ruang GIRA refers to Interactive Geometry Space of Augmented Reality, which reflects the application's characteristics as a learning medium that presents three-dimensional (3D) geometric objects interactively. This visualization is designed to support students' conceptual understanding, enhance their mathematical communication skills, and strengthen their self-efficacy. The development stages are described as follows.

Analysis Stage

The development of Augmented Reality–based learning media for the topic of polyhedra began with the analysis stage, which aimed to identify learning needs, student characteristics, and curriculum alignment. This stage served as the foundation for designing the Ruang GIRA media.

The results of the needs analysis indicated that the learning of polyhedra was still dominated by conventional methods using whiteboards and textbooks. As a result, the visualization of three-dimensional concepts had not been optimal. Students experienced difficulties in imagining spatial shapes, nets of solids, and the relationships among the elements of geometric solids. Therefore, an innovative learning medium was required to present objects concretely and interactively through visual representations.

The analysis of student characteristics showed that the spatial visualization ability of ninth-grade students varied, even though cognitively they had entered the formal operational stage. Students also demonstrated a high interest in the use of technology and smartphones. Consequently, Augmented Reality media was considered appropriate to support students' understanding of abstract geometric concepts.

Furthermore, the analysis of the Merdeka Curriculum for Grade IX Semester I revealed that the topic of polyhedra requires strong spatial visualization and conceptual understanding. Students' difficulties in relating three-dimensional shapes to their nets and in understanding spatial structures further emphasize the need for learning media that provide interactive three-dimensional visualization.

Design Stage

The design stage is an important phase in the development of learning media, as it aims to formulate an initial representation of the product systematically. At this stage, a storyboard was prepared as a reference for the display flow, navigation structure, and material presentation, thereby making the media development process more directed. The Augmented Reality features were implemented by developing the supporting software required for Android-based media. Unity 3D served as the primary platform for integrating all components of the Augmented Reality-based learning media. Vuforia was used as a Software Development Kit (SDK) to detect markers and display virtual objects in real time via the device's camera. Meanwhile, Blender was used to design and model three-dimensional objects, along with their animations, for display in AR media.

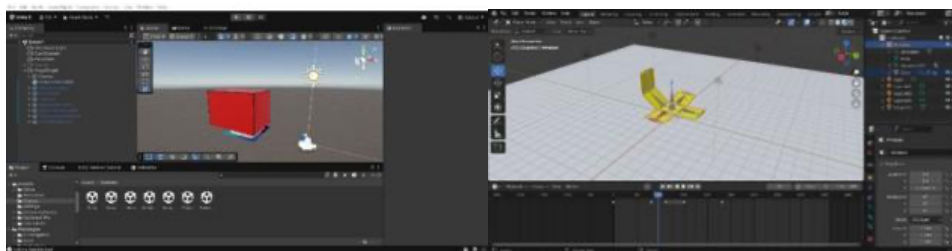


Figure 2. Unity 3D and Blender Interface

The combination of these three software tools enabled the development of AR media with interactive visual displays that are aligned with instructional needs.

Development Stage

At the development stage, the media design was realized as a tangible product: an AR-based learning media application. The development activities included the creation of three-dimensional models of polyhedra, such as cubes, rectangular prisms, and pyramids, which were

designed with accurate geometric proportions and structures as well as simple visual appearances to facilitate students' observation of the elements of geometric solids. These 3D models enabled direct interaction, including rotation, enlargement, and viewing objects from multiple perspectives, to support spatial understanding. Furthermore, all models were integrated into the Augmented Reality system using Unity 3D, resulting in an Android application (.apk) that includes a main menu, usage instructions, learning materials with marker-scanning features, visualizations of the elements and nets of geometric solids, and a developer profile menu. This application was designed to be easy to use and to support geometry learning in a more interactive and meaningful manner. The following are some of the displays available in the Ruang Gira application.



Figure 3. Several Displays in the Ruang Gira Application

The development of the Ruang Gira application in Unity 3D was conducted in several stages. After all required software had been installed, the initial step was to arrange the interface layout according to the storyboard developed during the design stage. The next stage involved preparing resources, including supporting files and libraries such as the Qualcomm Vuforia package, marker database, visual asset files (images, icons, and 3D models), and other supporting files.

After all resources were prepared and the interface layout was finalized, the process continued with system configuration and script development in C#. This coding process was required to manage interactive functions, marker data processing, 3D object calling, and navigation between menus. After all functions operated as designed, the application was exported to the .apk format via the build process, enabling installation and testing on Android smartphones. In addition to the technical development process, this stage involved assessing product quality through expert validity testing.

Table 2. Media Expert Validation

No.	Assessed Aspect	Mean Score	Category
1	Visual quality and application interaction	3,62	Highly Feasible
2	Learning effectiveness	3,54	Highly Feasible
3	Accessibility and ease of use	3,47	Highly Feasible
	Overall average	3,54	Highly Feasible

Media validation was conducted by two experts with competencies in the fields of instructional media development and educational technology. The assessment focused on three main aspects: visual quality and application interaction, learning effectiveness, and accessibility and ease of use of the media.

Based on the evaluation results, the aspect of visual quality and application interaction obtained an average score of 3.62, indicating that the visual appearance, interface design, and interactivity of the Augmented Reality Ruang Gira media were considered very good and capable of supporting user engagement. The learning effectiveness aspect obtained an average score of 3.54, suggesting that the media was considered effective in assisting the delivery of learning materials and supporting students' understanding of flat-sided solid geometry concepts.

through more visual and interactive representations. Meanwhile, the accessibility and ease-of-use aspect obtained an average score of 3.47, indicating that the application is relatively easy for students to operate using smartphone devices.

Overall, the Augmented Reality-based learning media Ruang Gira obtained an average score of 3.54, which falls into the very feasible category. These results indicate that the developed media has met the feasibility criteria in terms of media design, interactivity, and ease of use, making it suitable for use in the implementation stage of mathematics learning.

Table 3. Media Expert Validation

No.	Assessed Aspect	Mean Score	Category
1	Content	3,28	Highly Feasible
2	Didactic	3,52	Highly Feasible
3	Construction	3,47	Highly Feasible
4	Technical	3,41	Highly Feasible
	Overall average	3,42	Highly Feasible

The material evaluation was conducted by an expert with competence in the field of mathematics education. The assessment focused on four main aspects: content, didactic, construction, and technical aspects. The results indicate that the content aspect obtained an average score of 3.28, suggesting that the material presented is generally aligned with the basic competencies and learning indicators for the topic of flat-sided solid geometry, although several improvements were recommended, particularly regarding the completeness of examples and the emphasis on certain concepts.

The didactic aspect obtained an average score of 3.52, indicating that the presentation of the material within the media supports the learning process systematically and helps students understand concepts gradually. Furthermore, the construction aspect obtained an average score of 3.47, showing that the structure of the material presentation, the use of language, and the organization of examples and exercises are logically arranged and relatively easy for students to understand. In the technical aspect, the average score was 3.41, indicating that the use of mathematical symbols, terminology, and the presentation of the material are generally appropriate.

Overall, the Augmented Reality-based learning media Ruang Gira obtained an average score of 3.42, which falls into the very feasible category. These results indicate that the material presented in the media has met the feasibility criteria and can be used in the implementation stage of learning after several refinements are made in accordance with the experts' suggestions.

The media experts suggested that the application's initial display be labeled "Ruang Gira," as it had previously displayed only the term "Augmented Reality" without a clear product identity. In addition, the usage instruction section was revised by removing sections that were irrelevant or not applicable to the application. The media experts also highlighted the lack of word wrapping in the profile section, which resulted in uneven spacing, making it appear less neat and requiring correction to improve clarity and aesthetic quality.

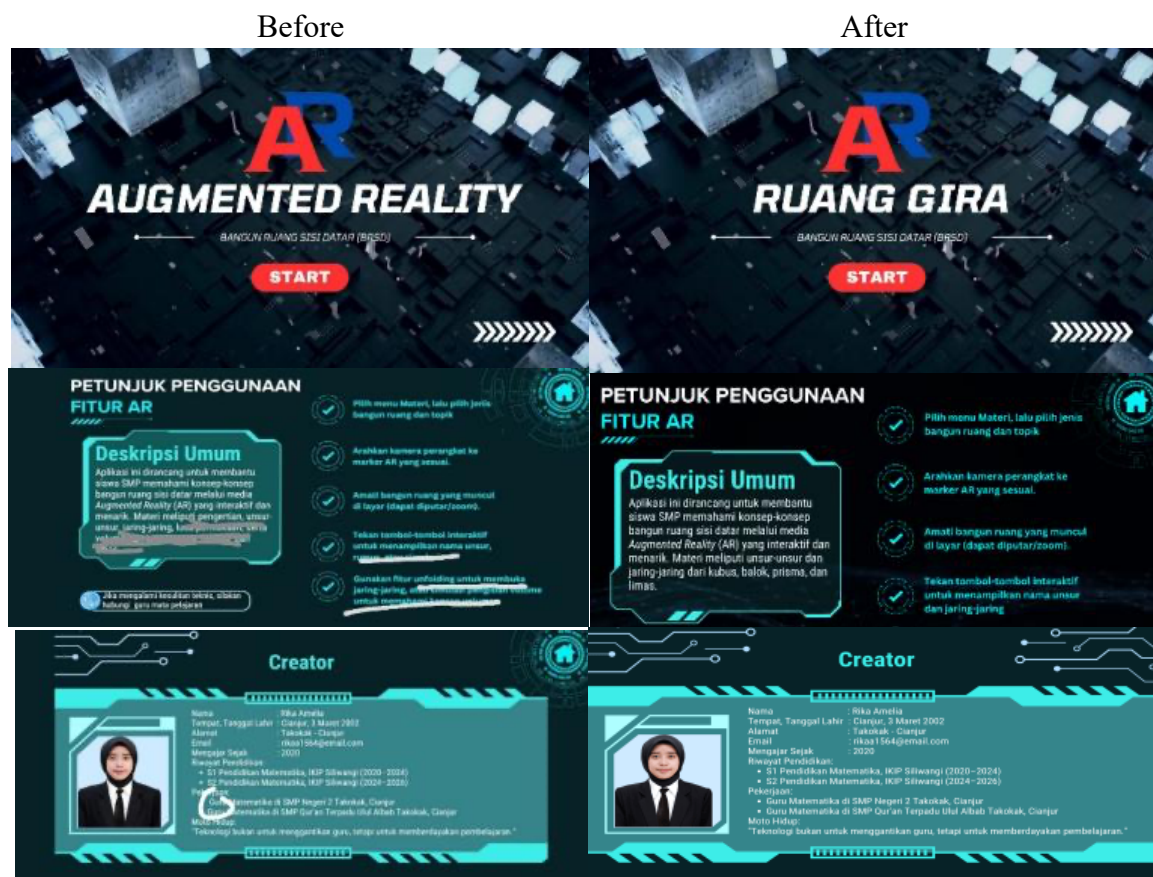


Figure 4. Comparison Before and After Revision

This learning media also received feedback from subject matter experts. The subject matter experts recommended that the content section include components related to surface area and volume calculations, so that it does not only focus on three-dimensional visualization, elements, and nets of geometric solids. However, because the scope of development at this stage was limited to these three aspects, adjustments to surface area and volume calculations are planned for the subsequent development stage.

Implementation Stage

During the implementation stage, learning was conducted using the Discovery Learning model with AR-based learning media in the experimental class, whereas the control class used the same material without AR. This stage aimed to test the effectiveness of AR-based learning media in improving students' mathematical communication skills and self-efficacy.

Mathematical Communication Skills Results

The effectiveness analysis was conducted by comparing pretest and posttest results and by calculating gains in mathematical communication skills between the two classes. The initial stage of the study began with the administration of an initial ability test (pretest) to students before the learning process started. This pretest was used to assess students' mathematical communication skills at the outset and to ensure that the experimental and control classes had comparable ability levels before the treatment was administered. The equivalence of initial abilities was an important prerequisite, enabling differences in final outcomes to be interpreted as the effect of the implemented treatment. After the entire sequence of learning activities had been completed, at the final meeting, students were given a final test (posttest). The posttest aimed to assess students' achievement in mathematical communication following participation

in the learning process. By comparing posttest and pretest results, the degree of improvement in each group's abilities can be identified. The mean pretest and posttest scores for both classes are presented in Table 9.

Table 4. Mean Pretest and Posttest Scores

No	Classes	Pretest	Posttest
1	Experimental	64.76	88,66
2	Control	64.14	71,59

Based on Table 4, the mean pretest scores of the experimental class (64.76) and the control class (64.14) show relatively similar results and fall into the moderate to low category. This indicates that students' mathematical communication skills before the treatment had not developed optimally and that the two groups had equivalent initial abilities. After the treatment was administered, the mean posttest score of the experimental class increased significantly to 88.66. Meanwhile, the control class also increased, with a lower mean score of 71.59. This difference in mean scores indicates that AR-based learning media within the Discovery Learning model have a stronger impact on the development of mathematical communication skills than learning without AR media. The pretest and posttest data were subsequently analyzed using SPSS software.

After obtaining the pretest and posttest data, the next step was to conduct a normality test to verify that the data were normally distributed. Normality testing is an important prerequisite in parametric statistical analysis, because the validity of mean difference test results strongly depends on the fulfillment of this assumption. The normality test in this study used the Shapiro–Wilk test at the 95% confidence level ($\alpha = 0.05$). The Shapiro–Wilk test was selected because the sample size in each class was fewer than 50 students ($n = 29$), making this test more sensitive and appropriate for detecting data distribution in small samples. The hypotheses proposed in this test were H_0 , which states that the data are normally distributed, and H_a , which states that the data are not normally distributed. The testing criteria stipulated that H_0 is accepted if $\text{Sig} > 0.05$ and rejected if $\text{Sig} \leq 0.05$. The results of the normality test for the pretest and posttest data are presented in Table 10 below.

Table 5. Normality Test of Pretest and Posttest Data

	Pre-Test			Posttest		
	Statistic	df	Sig.	Statistic	df	Sig.
Control	.976	29	.728	.961	29	.341
Experimental	.969	29	.533	.961	29	.341

Based on Table 5, the significance value of the pretest data in the control class was 0.728, and in the experimental class was 0.533. Both values exceeded 0.05; therefore, the pretest data in both classes were deemed normally distributed. This indicates that the initial condition of students' mathematical communication skills in both groups met the assumption of normal distribution. Furthermore, the results of the normality test on the posttest data indicated a p-value of 0.341 for the control class and 0.341 for the experimental class. Because both values were also greater than 0.05, the posttest data in both classes were declared to be normally distributed.

After the normality assumption was fulfilled, the next step was to conduct a homogeneity of variance test. This test aims to determine whether the variances of the data in the experimental and control classes are homogeneous. Homogeneity of variance is one of the prerequisites for using parametric tests, particularly the Independent Sample t-Test, because this test assumes that both groups have equal variances. The homogeneity test in this study was conducted using Levene's test (Based on Mean) with a significance level of $\alpha = 0.05$. The decision criteria were as follows: if the significance value (Sig.) > 0.05 , the variances of the two groups are declared homogeneous; conversely, if $\text{Sig.} \leq 0.05$, the variances of the two groups are not homogeneous.

The results of the homogeneity test for the pretest and posttest data are presented in Table 6 below.

Table 6. Homogeneity Test of Pretest and Posttest Data

Variable	Pretest (Sig).	Posttest (Sig)
Students' Mathematical Communication Skills	.687	.995

Based on Table 6, the significance value of Levene's test (Based on Mean) for the pretest data was 0.687, and for the posttest data was 0.995. Both values exceeded 0.05; therefore, the variances of students' mathematical communication skills in the experimental and control classes were homogeneous before and after the treatment. The homogeneity of variances in the pretest data further confirms that the two groups had comparable initial characteristics, not only in mean scores but also in dispersion. Meanwhile, the homogeneity of the posttest data indicates that although learning outcomes improved, the level of score variation between the groups remained equivalent.

With the assumptions of normality and homogeneity of variance met, the analysis could proceed using a parametric test, namely the independent-samples t-test. This test was used to examine whether there was a difference in the mean level of mathematical communication skills between students in the experimental class that used AR-based learning media based on the Discovery Learning model and the control class that used learning without such media.

The formulation of the hypotheses for the independent sample t-test on the pretest data is as follows: H_0 : There is no difference in the initial abilities of students who learn using AR-based learning media with the Discovery Learning model compared to students who learn without the media. H_a : There is a difference in the initial abilities of students who learn using Augmented Reality-based learning media with the Discovery Learning model compared to students who learn without the media. The testing criteria in the independent sample t-test are as follows: if the significance value (Sig.) > 0.05 , then H_0 is accepted; if the significance value (Sig.) ≤ 0.05 , then H_0 is rejected

Table 7. Independent Sample t Test Results for Pretest Data

	<i>t</i>	<i>df</i>	<i>Sig. (2-tailed)</i>
<i>Equal variances assumed</i>	.852	56	.398

The analysis results indicate a significance value of 0.398, which exceeds the 0.05 significance level. Statistically, the value of Sig. (2-tailed) = 0.398 > 0.05 indicates that there is no significant difference in the initial abilities of students in the experimental class and the control class. Thus, based on the results of the Independent Samples t-test, it can be concluded that students' initial abilities in both classes were equivalent prior to the learning treatment.

The formulation of the hypotheses for the independent sample t-test on the posttest data is as follows: H_0 : The achievement of mathematical communication skills of students who learn using AR-based learning media with the Discovery Learning model is not better than that of students who learn without the media. H_a : The achievement of mathematical communication skills of students who learn using AR-based learning media with the Discovery Learning model is better than that of students who learn without the media. The testing criteria in the independent sample t-test are as follows: if the significance value (Sig.) > 0.05 , then H_0 is accepted; if the significance value (Sig.) ≤ 0.05 , then H_0 is rejected.

Table 8. Independent Sample t Test Results for Posttest Data

	<i>t</i>	<i>df</i>	<i>Sig. (2-tailed)</i>
<i>Equal variances assumed</i>	24.517	56	.000

Based on the SPSS output in Table 8 above, it can be seen that the Sig. (2-tailed) The value is 0.000, which is less than 0.05. From this test, it can be concluded that H_0 is rejected, indicating that students who learned using AR-based learning media with the Discovery Learning model achieved higher mathematical communication skills than those who learned without the media.

The improvement of students' mathematical communication skills was analyzed using N-Gain values. The following presents the percentages and improvements in mathematical communication skills based on the overall N-Gain values.

Table 9. Percentage and Improvement of Mathematical Communication Skills Based on Overall N-Gain Values

Gain Range	Category	Number of Students	
		Experimental Class	Control Class
$g \geq 0,7$	High	11	0
$0,3 \leq g < 0,7$	Moderate	18	6
$g < 0,3$	Low	0	23

The results of the N-Gain calculation show that the improvement of mathematical communication skills in the experimental class falls within the moderate to high categories. Of the 29 students, 18 were in the moderate category (0.54–0.69) and 11 were in the high category (0.70–0.82), with no students in the low category. This distribution confirms that Augmented Reality-based learning using the Discovery Learning model is effective in promoting significant and evenly distributed improvements in mathematical communication skills. In contrast, in the control class, 23 of the 29 students were in the low category (–0.03–0.27), including one student with a negative value, and only 6 students reached the moderate category (0.30–0.38), with no students in the high category. The dominance of the low category indicates that learning without AR media support is less optimal in improving mathematical communication skills. These findings further support the conclusion that integrating Augmented Reality into the Discovery Learning model yields a greater improvement than conventional learning.

Self-Efficacy Results

In addition to examining students' mathematical communication skills, this study also investigates students' self-efficacy as an important variable that can influence success in learning mathematics. Self-efficacy data were obtained through a Likert-scale questionnaire, which were then converted from ordinal data into interval data using the Successive Interval method. This conversion process was carried out to ensure that the data met the requirements for further statistical analysis. Subsequently, the converted data were analyzed using IBM SPSS Statistics software. Based on the results of data processing, the mean scores of students' self-efficacy in the pretest and posttest are presented in Table 10.

Table 10. Mean Pretest and Posttest Scores

No	Classes	Pretest	Posttest
1	Experimental	1.67	3.07
2	Control	1.62	2.16

From the table 10, it can be seen that the average initial self-efficacy (pretest) scores of both classes are relatively similar, namely 1.67 for the experimental class and 1.62 for the control class. This indicates that the initial self-efficacy levels of students in both groups are comparable. However, after the treatment was administered, a significant increase was observed in the experimental class, with the mean reaching 3.07, while the control class only increased to 2.16. Thus, descriptively, it can be stated that the improvement in students' self-efficacy in the experimental class is higher than that in the control class.

To determine the significance of this difference, the first step conducted was a normality test using the Shapiro–Wilk test. The results of the normality test for both pretest and posttest data are as follows:

Table 11. Normality Test of Pretest and Posttest Data

	<i>Pre-Test</i>			<i>Posttest</i>		
<i>Shapiro-Wilk</i>	<i>Statistic</i>	<i>df</i>	<i>Sig.</i>	<i>Statistic</i>	<i>df</i>	<i>Sig.</i>
Experimental	.638	29	.000	.638	29	.000
Control	.635	29	.000	.628	29	.000

Since all significance values are less than 0.05 (Sig. < 0.05), it can be concluded that the data are not normally distributed. Therefore, the analysis was continued using a non-parametric statistical test, namely the Mann–Whitney test. The results of the Mann–Whitney test for the pretest and posttest data are presented in Table 12.

Table 12. Uji Mann Whitney for Pretest and Posttest Data

	<i>Pretest</i>	<i>Posttest</i>
Asymp. Sig. (2-tailed)	.794	.000

Based on these results, the pretest significance value is 0.794, which is greater than 0.05 (Sig. > 0.05). This indicates that there is no significant difference between the self-efficacy of students in the experimental and control classes before the treatment was given. In other words, both groups had equivalent initial conditions. Meanwhile, the posttest significance value is 0.000, which is less than 0.05 (Sig. < 0.05). This indicates that there is a significant difference between the self-efficacy of students in the experimental and control classes after the treatment was given. Therefore, it can be concluded that the treatment applied in the experimental class had a significant effect on improving students' self-efficacy. Overall, the results of this study indicate that the learning approach implemented in the experimental class not only improves students' mathematical communication skills but also effectively enhances their self-efficacy in learning mathematics, particularly on the topic of solid geometry (polyhedra).

To strengthen the analysis of the improvement in students' self-efficacy, the N-Gain was calculated to determine the magnitude of the increase after the treatment was administered. The N-Gain was computed based on the difference between pretest and posttest scores, which were then normalized, thereby providing a more accurate representation of the effectiveness of the learning process. Based on the descriptive analysis, the N-Gain values for both classes are as follows:

Table 13. Mean N-Gain Scores

Classes		Statistic	
Experimental	Mean		66.38
	95% Confidence Interval for Mean	Lower Bound	58.48
		Upper Bound	74.28
	Median		46.67
	Std. Deviation		20.766
Kelas Kontrol	Mean		19.11
	95% Confidence Interval for Mean	Lower Bound	9.24
		Upper Bound	28.98
	Median		.00
	Std. Deviation		25.942

Referring to the N-Gain interpretation criteria, a value of 66.38% in the experimental class falls into the moderate to high category, while a value of 19.11% in the control class is categorized as low. This indicates that the improvement in students' self-efficacy in the experimental class is significantly better than that in the control class. Furthermore, the 95% confidence interval for the experimental class ranges from 58.48 to 74.28, indicating that the improvement is relatively consistent among most students. In contrast, the control class has a lower confidence interval, ranging from 9.24 to 28.98, suggesting that the improvement is relatively small and less evenly distributed. In terms of data dispersion, the standard deviation in the experimental class is 20.766, whereas in the control class it is 25.942. This indicates that the variation in improvement in the control class is greater than that in the experimental class, meaning that the improvement among control class students is less uniform. This is further supported by the range value in the control class, which reaches 87, significantly higher than that of the experimental class, which is only 41. From the perspective of the median value, the experimental class has a median of 46.67, while the control class has a median of 0.00. The very low median in the control class indicates that most students did not experience a meaningful improvement. In contrast, in the experimental class, most students showed a relatively significant improvement.

Overall, the N-Gain analysis reinforces the previous findings that the learning approach implemented in the experimental class is more effective in improving students' self-efficacy compared to the control class. Therefore, it can be concluded that the treatment not only has statistical significance but also demonstrates high practical effectiveness in enhancing students' self-efficacy.

To obtain a more detailed description of the improvement in students' self-efficacy, the distribution of categories is as follows:

Table 13. Percentage and Improvement of Self-Efficacy on Overall N-Gain Values

Gain Range	Category	Number of Students	
		Experimental Class	Control Class
$g \geq 0,7$	High	14	1
$0,3 \leq g < 0,7$	Moderate	15	10
$g < 0,3$	Low	0	18

Based on these results, it can be observed that the majority of students in the experimental class fall into the moderate and high categories, with no students in the low category. This indicates that the learning approach implemented in the experimental class was able to provide a relatively even and significant improvement in students' self-efficacy. In contrast, in the control class, most students fall into the low category, while only a limited number of students reach the moderate category and very few achieve the high category. This suggests that the learning implemented in the control class was less effective in optimally improving students' self-efficacy. Overall, the distribution of N-Gain categories further strengthens the previous findings that the improvement in self-efficacy in the experimental class is not only higher on average but also more evenly distributed among students. In other words, the treatment applied in the experimental class has proven to be more effective in enhancing students' confidence in learning mathematics.

These findings suggest that the integration of Augmented Reality within the Discovery Learning model provides a more engaging and supportive learning environment, which contributes positively to students' confidence and motivation. The interactive and visual nature of AR enables students to explore mathematical concepts more independently, thereby strengthening their belief in their own abilities.

These findings confirm that Augmented Reality-based learning within the Discovery Learning model is more effective at strengthening students' self-efficacy because interactive, visual learning experiences enhance students' confidence, persistence, and readiness to face mathematical challenges.

Evaluation Stage

After the Augmented Reality-based learning media was implemented in the learning process, the next step was to analyze the data obtained from expert validation results, student responses, and student learning outcomes. Student responses were collected through a closed-ended questionnaire aimed at identifying the extent to which the media was able to attract students' attention, facilitate their understanding of the material, and increase their interest in learning mathematics.

The analysis results indicate that the use of Augmented Reality media provides positive contributions from both pedagogical and psychological perspectives in supporting students' learning processes. The detailed results of the students' responses are presented in Table 10.

Table 14. Student Response to The Learning Media

No.	Statement	Average Score	Positive Percentage	Category
1	The media display is attractive and easy to understand	3.48	87%	Very positive
2	The application is easy to operate via smartphone	3.41	85,3%	Very positive
3	Three-dimensional visualization helps in understanding polyhedra	3.55	88,8%	Very positive
4	The net feature helps in understanding the relationship between three-dimensional solids and plane figures	3.46	86,5%	Very positive
5	This media increases my learning interest in polyhedra material	3.38	84,5%	Positive
6	This media helps me learn independently	3.32	83%	Positive
	Overall average	3.43	85,9%	Very positive

Based on the results of the student response questionnaire regarding the use of the Augmented Reality-based learning media Ruang Gira, the overall average score obtained was 3.43 with a positive response percentage of 85.9%, which falls into the very positive category. These results indicate that students provided very favorable responses to the use of the media in mathematics learning.

The highest score was found in the statement that 3D visualization helps in understanding the shapes of flat-sided solid geometry, with an average score of 3.55 and a positive percentage of 88.8%. This result indicates that the three-dimensional visualization feature in the Augmented Reality media helps students understand spatial geometry concepts in a more concrete way. In addition, aspects related to the attractive and easy-to-understand media display, as well as the ease of operating the application through smartphones, also received very positive ratings.

Meanwhile, the aspects related to increasing learning interest and independent learning ability were categorized as positive, indicating that the media not only supports conceptual understanding but also motivates students to become more active in the learning process. Overall, these results show that the Augmented Reality-based learning media Ruang Gira received very positive responses from students and has the potential to support a more interactive and engaging mathematics learning process.

In addition to quantitative findings, qualitative observations during classroom implementation also revealed diverse learning experiences among students. Some students experienced minor

delays in marker tracking, especially in unstable or dim lighting conditions. This sometimes caused 3D objects to appear late, prompting students to adjust the position of the device or their viewing angle so that the markers were detected correctly. Despite these technical glitches, students remained enthusiastic and continued to explore the application's features.

In addition, some students reported that the interface became easy to understand after two or three attempts. Although some students initially had difficulty navigating the AR buttons and commands, repeated practice allowed them to operate the application with more confidence and independence, with little guidance from the teacher.

The most memorable learning moment occurred when students observed the opening and closing animations of the polyhedron net. Many expressed amazement and excitement, as the animations allowed them to clearly see the relationship between the three-dimensional shape and its net. This visual experience helped develop spatial understanding that is often difficult to achieve through conventional instructional resources.

Discussions

Analysis Stage

The findings at the analysis stage indicate that the development of Augmented Reality (AR) based learning media for the topic of polyhedra addresses real needs in ninth-grade mathematics learning, particularly related to limitations in three-dimensional concept visualization. This is in line with the findings of Marian et al. (2025), which states that AR can serve as an effective means of strengthening the understanding of abstract geometric concepts. Conceptually, these results are directly related to the initial objective of the study, namely, to design learning media that can bridge the gap between the abstract nature of spatial geometry content and students' spatial representation abilities.

The dominance of conventional methods identified during the analysis stage indicates an instructional gap between the material's demands and the learning strategies used. This finding is consistent with the study by Maghfiroh and Qothrunnada (2024), which states that conventional media are insufficient in helping students understand spatial transformations between three-dimensional and two-dimensional representations. Polyhedra require the ability to imagine objects from various perspectives, understand the relationships among their elements, and relate three-dimensional solids to their corresponding nets. When learning relies solely on two-dimensional images on the blackboard or in textbooks, students tend to construct understanding partially and procedurally. In this context, the presence of AR media has pedagogical significance because it enables the transformation of abstract concepts into concrete and manipulable visual representations. This is consistent with dual coding theory, which states that information is more easily understood when it is presented simultaneously through verbal and visual channels (Paivio, 1991).

From the perspective of student characteristics, although ninth-grade students have cognitively entered the formal operational stage, the analysis indicates that their spatial visualization abilities remain heterogeneous. This finding reinforces the view that formal cognitive readiness does not automatically guarantee mastery of complex spatial abilities (Battista et al., 2018). AR media function as cognitive support, helping students build mental models of geometric solids through direct interaction with three-dimensional objects. Thus, AR not only serves as a visual aid, but also serves as a means to strengthen students' active knowledge construction processes (Hadiyani et al., 2025).

In addition, students' high interest in technology and smartphone use provides strong justification for selecting the AR platform as a learning medium. The integration of technology closely connected to students' daily lives has the potential to increase engagement and learning

motivation, thereby positively affecting the quality of conceptual understanding. These findings are consistent with various studies reporting that AR-based learning can enhance engagement and understanding of geometric concepts because it provides immersive and interactive learning experiences (Ibáñez & Delgado-Kloos, 2018; Radu, 2014)

When viewed through the lens of the Merdeka Curriculum, which emphasizes conceptual understanding, spatial thinking, and meaningful learning, the development of Ruang Gira media becomes increasingly relevant. Students' difficulties in relating geometric solids to their nets indicate that static visualization is insufficient. Augmented Reality enables dynamic, interactive exploration of objects, aligning more closely with the characteristics of geometry content. Overall, the development of AR-based media is strategic because it addresses pedagogical needs, supports curriculum achievement, and effectively improves the quality of learning on polyhedra.

Design Stage

The design stage indicates that a systematic Augmented Reality media design is a key factor in ensuring alignment among learning objectives, content, and learning experiences. The storyboard functions as a bridge between needs analysis and technical development, while also ensuring that the flow of content, interactions, and navigation is aligned with the conceptual logic of spatial geometry. A well-planned design also minimizes the risk of cognitive overload caused by visual complexity, allowing students to focus more effectively on conceptual understanding. These findings affirm that the quality of instructional design determines the success of technology integration in mathematics learning.

The selection of Unity 3D as the main development platform has significant implications for the quality of the resulting media. Unity enables the integration of various multimedia components and real-time interactions; thus, the learning experience is not passive in nature (Muhamad Alghivary et al., 2024). From the perspective of the initial research objectives, the use of Unity supports the creation of responsive and interactive learning media, which aligns with the characteristics of polyhedra material that require object manipulation. These results are consistent with reports from several studies that emphasize that game engine platforms such as Unity are effective for developing educational AR media due to their flexibility and capability in handling dynamic three-dimensional visualization (Ibáñez & Delgado-Kloos, 2018; Kim et al., 2014).

The use of Vuforia as a supporting SDK contributes to the accuracy and stability of marker-based virtual object rendering. From a scientific perspective, the system's ability to detect markers precisely directly affects the continuity of students' interactions with three-dimensional objects. When objects appear and interact stably, students are better able to construct mental representations of the geometric solids being studied. This is important because technical disruptions during the visualization stage can impede learning and reduce students' motivation. These findings are consistent with the study by Radu (2014), which states that tracking quality and visual stability are crucial factors in the effectiveness of AR-based learning. The use of Blender in designing three-dimensional models and animations ensures the accuracy of shapes, proportions, and visual details of geometric solids, thereby minimizing the risk of misconceptions in geometry learning. The integration of Unity, Vuforia, and Blender reflects an alignment between technical and pedagogical needs, rather than merely practical considerations. Overall, the design stage confirms that the effectiveness of Augmented Reality media is strongly determined by the quality of a structured, learning-goal-oriented initial design, which enables meaningful understanding of geometric concepts.

Development Stage

The main findings at the development stage indicate that the developed AR-based learning media successfully bridged the gap between the abstract nature of polyhedra material and students' need for concrete visual representations. Conceptually, these results confirm that the initial research objective of producing AR media that are feasible, practical, and pedagogically relevant can be achieved through media development that emphasizes visual accuracy, interactivity, and ease of use (Anwari et al., 2020). From a pedagogical perspective, students' ability to manipulate three-dimensional objects by rotating, enlarging, and observing them from various angles has important implications for the development of spatial understanding. Such interactions enable students to develop more stable mental representations of the structures of geometric solids, which are difficult to achieve through two-dimensional images in textbooks. Scientifically, these findings can be interpreted as evidence that Augmented Reality functions as a representational bridge linking concrete visual experiences to formal geometric concepts. This is consistent with multimedia learning theory, which emphasizes that combining dynamic visuals with active interaction can reduce cognitive load and enhance conceptual understanding (Mayer & Fiorella, 2022).

The expert validation results reinforce the significance of media development from two perspectives: technical quality and content quality. The very feasible score from media experts indicates that interactivity and visual design aspects are not only aesthetic elements, but also play a direct role in supporting learning effectiveness. Meanwhile, the subject-matter experts' assessment indicates that curriculum alignment and conceptual sequencing have been met, although the depth of the material can still be expanded. These findings indicate that focusing on three-dimensional visualization as the core of the media was an appropriate decision at the initial development stage, because visualization is a primary need for students in learning polyhedra. In other words, limiting the scope of the material strengthens the media's function as a conceptual support tool rather than as a substitute for textbooks.

The feedback from the validators, addressed through revisions, demonstrates the importance of an iterative approach to developing learning media. Revisions to aspects of navigation, usage instructions, and visual consistency have direct implications for the practicality of media use in the classroom. This indicates that the success of technology-based learning media is determined not solely by the superiority of its features but also by the clarity of the interface and the quality of the user experience. These findings are consistent with previous research reports stating that usability is a determining factor in the adoption of AR media in educational contexts (Radu, 2014).

Implementation Stage

The integration of Augmented Reality with the Discovery Learning model has been shown to significantly improve students' mathematical communication skills and self-efficacy compared with learning without media. The equivalence of initial abilities ensured that differences in final outcomes were the effect of the treatment. These findings confirm that interactive visual support and conceptual exploration play an important role in optimizing students' ability to communicate mathematical ideas. Pedagogically, the superiority of the experimental class on posttest achievement and N-Gain values indicates that AR functions as a cognitive scaffold, helping students gradually build conceptual understanding. Interactive three-dimensional visualization enables students to connect symbols, images, and mathematical language in a more meaningful way. In the context of Discovery Learning, Augmented Reality enriches the stages of data collection and data processing, because students do not merely observe passively, but also manipulate objects and independently discover relationships among the elements of

geometric solids. This process aligns with the constructivist perspective, which emphasizes that knowledge is constructed through active exploration and discovery (Bruner, 1961).

The dominance of moderate to high N-Gain categories in the experimental class, along with the absence of students in the low category, indicates that this approach is inclusive and provides benefits to almost all students. In contrast, the low level of improvement in the control class reflects the limitations of conventional learning in facilitating mathematical communication, particularly for content that requires strong spatial visualization skills. These findings are consistent with various previous studies reporting that AR is effective in enhancing mathematical understanding and communication because it can concretize abstract concepts and strengthen visual representations (Ibáñez & Delgado-Kloos, 2018; Yoon et al., 2017).

In addition to cognitive aspects, the improvement of students' self-efficacy in the experimental class has psychological implications that are equally important. The consistent improvement across all indicators of self-confidence, expectations of success, persistence, courage in facing challenges, and interaction ability indicates that AR-based learning experiences not only enhance learning outcomes but also build students' confidence in learning mathematics. Theoretically, this can be explained through Bandura's self-efficacy theory, which states that direct mastery experiences are the primary source of self-belief formation (Bandura, 1997). Direct interaction with AR objects and students' success in independently discovering concepts provides positive learning experiences that strengthen their self-efficacy.

The difference in self-efficacy improvement between the experimental and control classes further confirms that Discovery Learning without adequate visual media support is not yet optimal in building students' confidence. Augmented Reality plays a role in creating a safer learning environment for exploration, reducing anxiety toward making mistakes, and encouraging discussion and interaction among students. These findings are consistent with studies reporting that interactive technologies can enhance students' motivation, engagement, and confidence in mathematics learning (Radianti et al., 2020; Wu et al., 2013).

Overall, these findings align with the international literature emphasizing the advantages of Augmented Reality in discovery-based learning. This study provides empirical evidence that the integration of AR and Discovery Learning simultaneously enhances both the cognitive dimension of mathematical communication skills and the affective dimension of self-efficacy. Therefore, this approach can be regarded as a comprehensive strategy for addressing the challenges of learning abstract geometry that requires spatial abilities at the junior high school level.

Furthermore, the findings of this study are consistent with those of Rahmi et al. (2017), which indicate a positive relationship between students' self-efficacy in mathematics and their mathematical communication skills. High self-efficacy plays an important role in enhancing students' confidence when dealing with various mathematical problems, enabling them to express ideas more confidently, explain solution procedures clearly, and defend their mathematical arguments effectively. Moreover, students with high self-efficacy tend to have better learning motivation, are more resilient when facing difficulties, and are able to apply appropriate strategies in problem-solving. This directly impacts their mathematical communication skills, as they are not only قادر of finding solutions but also able to articulate their thinking processes in a systematic, logical, and comprehensible manner.

In contrast, students with low self-efficacy tend to doubt their own abilities, resulting in a lack of confidence in expressing opinions or explaining mathematical ideas. This condition leads to less developed mathematical communication skills, as students are more likely to remain passive or avoid active participation in the learning process. Therefore, the improvement in self-efficacy observed in the experimental class in this study contributes to the enhancement of

students' mathematical communication skills. This finding reinforces the notion that self-efficacy is not merely a supporting factor, but a crucial aspect influencing students' success in mathematics learning, particularly in effectively communicating mathematical ideas.

Evaluation Stage

The evaluation stage indicates that integrating formative and summative evaluation is crucial for ensuring the quality and effectiveness of Augmented Reality media. Continuous formative evaluation enables iterative improvements, ensuring alignment among learning objectives, student characteristics, and technological features. Meanwhile, summative evaluation through posttests, response questionnaires, and self-efficacy measures provides a comprehensive overview of cognitive and affective impacts. This multidimensional approach confirms that AR media not only improve learning outcomes but also build meaningful learning experiences and students' confidence in a holistic manner.

When linked to findings from other studies, the formative and summative evaluation results in this study are consistent with various studies stating that the development of technology-based media is more effective when accompanied by continuous evaluation and comprehensive final evaluation. Several previous studies have reported that the combination of formative and summative evaluation can improve the quality of AR-based learning products, both from technical and pedagogical perspectives, because developers have opportunities to refine the media based on real user needs (Branch, 2009; Richey & Klein, 2014). Thus, the results of this study reinforce these findings in the context of junior high school mathematics learning.

The evaluation stage in this study is strategic because it ensures that the Augmented Reality media are effective, relevant, and have a positive impact. The systematic implementation of formative and summative evaluation can connect design, implementation, and learning outcomes, thereby making the developed media feasible to be applied more widely in mathematics learning.

CONCLUSION

Based on the research findings and discussions that have been conducted, several conclusions can be drawn as follows:

1. This study successfully developed a learning medium called Ruang GIRA (Geometry Interactive Reality Augmented) based on Augmented Reality (AR) for the topic of polyhedra at the junior high school level. The developed media has met the feasibility criteria and is appropriate for use in the learning process. Future development is expected to enhance its features by adding more interactive elements, such as the integration of surface area and volume calculations directly within the application.
2. The use of the Ruang GIRA media combined with the Discovery Learning model has been proven effective in improving students' mathematical communication skills, as indicated by the improvement in learning outcomes and the significant differences between the experimental and control classes.
3. Learning using the Ruang GIRA media has also been proven effective in improving students' self-efficacy. This is evidenced by the increase in posttest scores, the results of statistical tests, and the N-Gain values, which indicate improvements in the moderate to high categories in the experimental class.

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