Development of an Augmented Reality-Integrated Student Worksheet (LKPD) to Enhance Mathematics Learning Outcomes

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ABSTRACT

This study aims to develop and assess the quality of an Augmented Reality-Integrated Student Worksheet (LKPD) to enhance seventh-grade students' mathematics learning outcomes in spatial geometry. The research follows the Plomp development model, consisting of four phases: preliminary investigation, design, realization, and test-evaluation-revision. The LKPD was validated by three experts, including two mathematics education specialists and one instructional design expert. Practicality tests were conducted with one mathematics teacher and 31 students from SMP Negeri 16 Cirebon. The validation results indicate that the LKPD is highly valid, with a content validity score of 87.56% and a design validity score of 87.22%. Practicality tests showed positive responses from teachers (80%) and students (72.30% in small groups and 77.64% in field trials). Based on pre-test and post-test results, effectiveness testing yielded an N-Gain score of 0.58, categorized as moderate effectiveness. These findings suggest that the Augmented Reality-Integrated LKPD is a feasible and effective learning tool for mathematics education. However, limitations include compatibility issues with Android versions above 10 and dependency on coloured markers for AR recognition. Future research should focus on improving AR functionality for broader accessibility.

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1. INTRODUCTION

Education is a human effort to develop individuals' physical and mental potential in harmony with the values that apply in society and culture. As an essential pillar of human development, education is responsible for preparing and improving the quality of human resources for nation-building. The general goal of education is to improve individuals' ability to think critically, innovatively, and adaptively so that they can solve various problems and find practical solutions [1]. Mathematics is a very important field of education because it is fundamental in various other disciplines, including science and technology. In addition, mathematics plays a crucial role in everyday decision-making as it trains logical thinking, analytical, and problem-solving skills and enhances decision-making abilities, which are essential in daily life.

Education in Indonesia faces significant challenges related to low learning achievement in mathematics subjects [2]. Various international studies have shown that the level of numeracy literacy of students in Indonesia is still relatively low compared to other countries. This issue is particularly concerning as mathematical literacy is crucial for competitiveness in the global workforce. Mathematical literacy, the ability to apply mathematical concepts to real-world situations, is directly linked to learning outcomes. A lack of mathematical literacy affects students' academic performance and limits their ability to function effectively in a knowledge-based economy. To overcome these problems, the government has taken various initiatives, including implementing the National Assessment (AN) in 2021 to assess the quality of schools [3]. According to the results of the latest Programme for International Student Assessment (PISA) study in 2022, Indonesia has experienced an increase in ranking by 5-6 positions compared to 2018. However, despite this progress, the results show that there are still significant challenges in improving learning outcomes internationally, especially in mathematical literacy, which the impact of the COVID-19 pandemic has further exacerbated. The test results showed that the average mathematics score of students was 366, a decrease of 13 points from 376 in PISA in 2018. This score is below the average set by PISA for math ability, which is 468 [4]. Based on these results, Indonesia ranks 12th at the bottom in mathematics ability with an average score of 366. Research conducted by Wati and Nurcahyo [5] revealed that one of the most challenging aspects for students to master mathematics is geometry, especially in the Minimum Competency Assessment. Geometry is a part of mathematics that is often considered abstract and challenging for students to understand, which underscores the need for innovative learning methods to make it more interesting and easy to understand [6].

According to Bagus et al. [2], the low learning outcomes of students in mathematics are caused by the dominance of conventional learning methods that are still one-way and the lack of use of interactive learning media. This causes learning to be less interesting, so students tend to be passive. Along with technology development, digital-based learning media is a potential solution for increasing student involvement in mathematics learning [7], [8], [9], [10]. The learning process in the classroom cannot be separated from the use of learning media or teaching aids [11]. Good learning media can increase students' understanding of abstract concepts in mathematics by presenting them in a more concrete visual form.

Furthermore, integrating digital learning media can enhance mathematical literacy by enabling students to apply mathematical concepts interactively, thus improving their overall learning outcomes. However, one of the disadvantages of using conventional teaching aids is the need for longer preparation time, limited materials, and difficulties in maintenance and storage [12]. These challenges indicate the urgency for more effective and efficient technology-based learning media innovations to be developed and implemented.

Technological developments in education can be applied as learning media used in the learning process, especially in mathematics learning [13]. Technology improves learning effectiveness by providing a more interactive and engaging learning experience [14], [15], [16]. To keep up with this development, there is a need for renewal in learning methods and media [17]. Technology in this digital era is increasingly integrated into daily life, including education. Currently, technology-based learning systems have begun to be implemented in various educational institutions [8]. One of the rapidly growing uses of technology is Augmented Reality (AR), which combines the real world with virtual elements in the form of two or three dimensions in real time [18]. AR has great educational potential, increasing student engagement, facilitating the exploration of abstract concepts, and creating a more immersive learning experience [19]. Students can better understand mathematical concepts by integrating AR into mathematics learning, improving their mathematical literacy and learning outcomes. Moreover, the development of Augmented Reality technology has extended to creating Android-based learning media to support various educational needs.

Several studies have developed Augmented Reality-based learning media, but they still have limitations. For example, research by Ningsih et al. [13] only focuses on visualizing three-dimensional objects in mathematics without integrating them into the interactive learning process. Similarly, Listiawan and Antoni [20] developed an Augmented Reality application that only visualizes geometric transformations, while Arifin et al. [21] developed AR-based learning media limited to improving students' spatial abilities. In addition, research by Rozi et al. [22] succeeded in developing AR with a more complex visual display, but the focus is still limited to evaluating product quality without testing its effectiveness in authentic learning. Irmayanti et al. [23] also developed AR applications, but they still face limitations in their use in the classroom. Another research by Nurhasanah [24] attempts to develop AR with an ethnomathematical approach, but it has not yet been fully integrated into the form of Student Worksheets (LKPD) as a systematic learning instrument.

Of these several studies, no one has specifically developed an Augmented Reality (AR) integrated LKPD (*Lembar Kerja Peserta Didik*) as part of an interactive learning strategy in mathematics. Thus, a significant gap exists in integrating AR with structured learning materials. Given the importance of mathematical literacy in improving student learning outcomes, developing an AR-integrated LKPD is expected to provide an innovative solution for enhancing students' conceptual understanding and problem-solving skills. Therefore, this study aims to develop and assess the quality of LKPD integrated with Android-based Augmented Reality technology to improve students' mathematics learning outcomes. This study assesses the feasibility of LKPD in terms of validity and practicality and measures its effectiveness in improving understanding and learning outcomes of mathematics. By bridging this gap, the results of this study are expected to provide recommendations for educators in developing technology-based teaching material innovations, especially in mathematics learning at the secondary school level.

2. METHOD

This research is a research and development (R&D). The development model used is the Plomp model, which is known as a flexible and systematic model in the development of technology-based teaching materials. According to Rochmad [25], the Plomp model is more flexible than the Four-D model because it can be adjusted to the research characteristics through development steps in each stage. The model also allows iterative evaluation to improve each stage before further implementation. The Plomp model comprises five phases: preliminary investigation, design, realization/construction, test, evaluation, revision, and implementation. However, in this study, the Plomp model was only used until the fourth phase, without the implementation stage, due to the limited time of the research and the main focus on the validation and effectiveness test of the developed product.

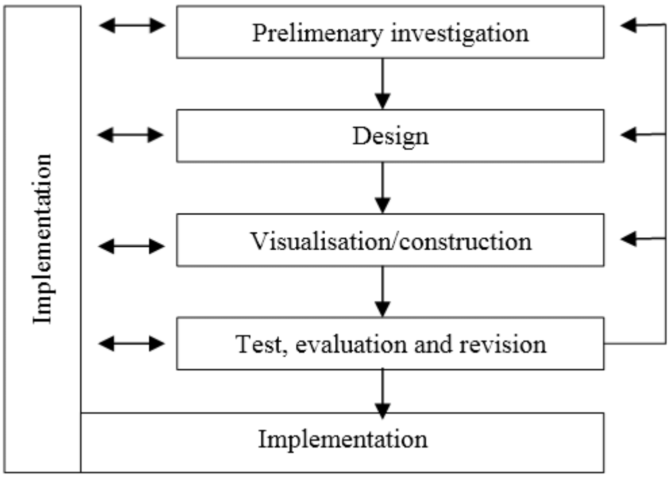

Figure 1. Plomp Development Model

The initial investigation phase aims to identify the need to develop AR-based learning media. This phase is divided into two stages: the analysis of needs or problems and the curriculum analysis. A needs analysis was carried out through observation in schools to find out the use of learning media in the teaching and learning process, the obstacles faced by teachers and students in understanding the concept of spatial geometry, and factors that affect the effectiveness of mathematics learning. In addition, interviews were conducted with educators to dig deeper into the challenges of teaching geometry material and opportunities for the use of technology in learning. Curriculum analysis examines the learning outcomes that students must master based on the Independent Curriculum, especially in the geometry of building space. This analysis includes the identification of essential competencies, the structure of the material content, and the appropriate learning approach to be applied in the development of AR-based LKPD.

The design phase aims to develop a strategy for developing LKPD based on Augmented Reality (AR). At this stage, the initial design of the LKPD is carried out by considering a systematic structure and a strong pedagogy. The structure of the LKPD is compiled, including several main parts, namely the front cover containing the title and user identity, preface, table of contents, learning achievements, learning objectives, instructions for using LKPD and AR, supporting materials, problem-solving steps, learning evaluation, and bibliography. In addition, the design stage also involves the preparation of research instruments, such as validity and practicality questionnaires, as well as learning outcome tests that will be used to measure the effectiveness of LKPD in improving students' understanding.

In the realization/construction phase, the design results are implemented as authentic products. In this phase, an Android-based Augmented Reality (AR) integrated LKPD is developed using a combination of graphic design software and relevant AR applications. The LKPD design was created using Canva, while the Augmented Reality object was developed using the Augmented Reality Augmented Reality application Build a Space. The LKPD products are then printed in colour format on A4 size HVS paper to ensure optimal visualization and support effective scanning of AR markers. Before the pilot phase, the development team and experts internally evaluated the product, consisting of one mathematics education lecturer and two mathematics teachers. The evaluation was conducted through a panel discussion and an initial feasibility assessment using a rubric covering design aspects, content clarity, and integrating AR features. The feedback from this evaluation was used to make revisions before proceeding to further trials.

The test, evaluation, and revision phase aims to evaluate the quality of the LKPD developed based on three main aspects: validity, practicality, and effectiveness. Before being used in learning activities, the LKPD was validated by a team of experts consisting of two mathematics education specialists and one instructional design expert. The material experts were selected based on their expertise in mathematics curriculum development and pedagogical strategies, while the design expert was chosen for their proficiency in educational media design and digital learning tools. Their evaluations focused on content accuracy, instructional materials clarity, and the AR integration's effectiveness. Validation was carried out using a Likert scale questionnaire that measured content eligibility, language, and presentation components for material experts and aspects of writing design, content design, and LKPD characteristics for design experts. Three independent validators assess each aspect to ensure the objectivity of the results. Three independent validators assess each aspect to ensure the objectivity of the results. These validators were selected based on their expertise and impartiality, ensuring they had no direct involvement in developing the LKPD. The criteria for selecting independent validators included a minimum of five years of experience in mathematics education or instructional design, prior involvement in evaluating educational materials, and an academic background relevant to the subject matter.

After validation and revision based on input from the expert team, the LKPD product was tested in three stages: individual, small group, and field trials. Individual trials were carried out by involving a grade VII mathematics teacher to evaluate the practical aspects from the educator's point of view. Furthermore, a small group trial involved nine learners with varying ability levels (low, medium, and high), which were determined based on their prior mathematics test scores. A diagnostic test was conducted before the trial to classify students into these categories, ensuring a representative sample for evaluating the initial response to using LKPD. In the last stage, a field trial was carried out on 22 grade VII students to measure the practicality and effectiveness of LKPD in authentic learning.

This research was conducted at SMP Negeri 16 Cirebon City, involving one mathematics teacher and a total of 31 seventh-grade students from class VII D. The research was carried out in stages, where initial trials were conducted with a small group of nine students with varying ability levels (low, medium, and high), followed by a field trial involving all 31 students to assess the practicality and effectiveness of the LKPD. The data collection techniques used in this study include interviews, observations, questionnaires, and learning outcome tests. Interviews are conducted during the initial investigation phase to determine the learning needs and challenges in teaching mathematics. Observations were made during the trial to see how LKPD was used in learning activities. Questionnaires are given to teachers and students to assess practical aspects while learning outcome tests are used to measure the effectiveness of LKPD in improving students' understanding of geometry concepts.

The data collection instruments used in this study consist of a design expert validation questionnaire, a material expert validation questionnaire, a teacher and student practicality questionnaire, and a learning outcome test in the form of description (essay) questions. Two mathematics education experts also validated the learning outcome test to ensure its alignment with the curriculum, clarity of questions, and appropriateness for measuring students' understanding of spatial geometry concepts. The data obtained were analyzed using qualitative and quantitative descriptive analysis techniques. Qualitative descriptive analysis was used to evaluate the results of interviews, suggestions, expert comments, and observations during the trial. Meanwhile, quantitative descriptive analysis was used to process data from the LKPD product validation questionnaire, teacher and student responses to the practicality of LKPD, and improvement of student learning outcomes based on the difference in pre-test and post-test scores.

The questionnaire data used the Likert scale, which was then converted into percentages using the following formula adapted from Arikunto [26]:

$$P(\%) = \frac{Score\ obtained}{Maximum\ score} x100\% \quad (1)$$

Furthermore, the percentage is interpreted based on the product validation criteria adapted from Riduwan [27], which can be seen in Table 1. as follows:

Table 1. Development Product Assessment Criteria

Interval	Criterion
0% - 20%	Very invalid/very impractical
21% - 40%	Invalid/Impractical
41% - 60%	Valid Enough/Practical Enough
61% - 80%	Valid/Practice
81% - 100%	Very Valid/Very Practical

To measure the improvement of learning outcomes, pre-test and post-test data were analyzed using the N-Gain formula and categorized based on the N-Gain score interpretation criteria from Kusuma et al. [28], as shown in Table 2. The measurement of the N-Gain value uses the following formula:

$$N - Gain = \frac{Posttest\ score - Pretest\ score}{Ideal\ score - Pretest\ score} \quad (2)$$

Table 2. N-Gain Score Criteria

Interval	Category
N-Gain > 0.70	high
0.30 < N-Gain ≤ 0.70	moderate
N-Gain < 0.30	low

Table 3 below shows the category of effectiveness interpretation based on the N-Gain value adapted from Rozi et al. [22].

Table 3. Categories Interpretation of N-Gain Effectiveness

Interval	Criteria
< 40	Ineffective
40 – 55	Less Effective
56 – 75	Quite Effective
> 76	Effective

3. RESULTS AND DISCUSSION

3.1. Results

The result of this study is an Android-based Augmented Reality (AR) integrated Student Worksheet (LKPD) developed through the Plomp model. The development of this LKPD is based on preliminary findings that show that the lack of interactive teaching materials in mathematics learning causes students to experience difficulties in understanding the concept of spatial geometry. The interview results found that students felt that mathematics learning was still monotonous and less interesting, mainly because there was no development of technology-based learning media in schools. Although students can bring mobile phones to school, their use in supporting learning is still limited. Therefore, the development of augmented reality-based LKPD is expected to be an innovative solution to improve students' mathematics understanding and learning outcomes.

The results of the curriculum analysis show that the curriculum used in schools is the Independent Curriculum, which emphasizes project-based learning to strengthen students' soft skills and character following the profile of Pancasila Students. In this curriculum, learning emphasizes literacy and numeracy so that students are encouraged to find concepts independently through exploration and problem-solving. This is in line with the research of Pratycia et al. [29], which states that the Independent Curriculum provides flexibility for educators to develop more interactive and contextual teaching material to improve students' conceptual understanding. Therefore, developing Augmented Reality (AR)--based LKPD based on Android is relevant to the learning approach in the Independent Curriculum.

The initial investigation phase findings were followed up by designing and developing an LKPD that integrates AR technology to help students visualize the concept of building space more concretely and interactively. In the design process, content that suits the needs of students is selected, and Augmented Reality markers are developed that can be used to display geometric objects in three-dimensional form. The LKPD was designed using the

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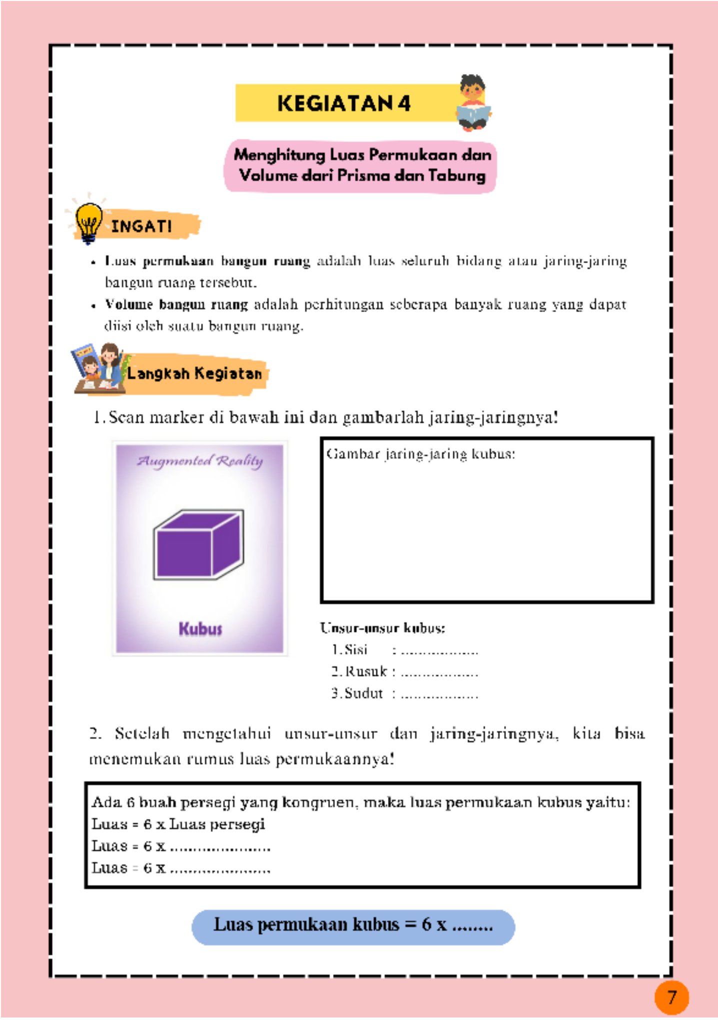
Canva application to ensure visual quality and readability. At the same time, augmented reality was developed through the LKPD application, which allows students to scan markers in the LKPD to see the appearance of 3D objects in real time. However, in its implementation, some technical limitations were found, such as the AR application, which is only compatible with Android version 10 and below, and markers that can only be recognized if printed in colour instead of black and white. The following is an example of an LKPD that integrates augmented reality:


KEGIATAN 4

Menghitung Luas Permukaan dan Volume dari Prisma dan Tabung

INGAT!

- **Luas permukaan bangun ruang** adalah luas seluruh bidang atau jaring-jaring bangun ruang tersebut.
- **Volume bangun ruang** adalah perhitungan seberapa banyak ruang yang dapat diisi oleh suatu bangun ruang.

Langkah Kegiatan

1. Scan marker di bawah ini dan gambarlah jaring-jaringnya!

Augmented Reality

Kubus

Gambar jaring-jaring kubus:

Unsur-unsur kubus:
1. Sisi : ....
2. Rusuk : ....
3. Sudut : ....

2. Setelah mengetahui unsur-unsur dan jaring-jaringnya, kita bisa menemukan rumus luas permukaannya!

Ada 6 buah persegi yang kongruen, maka luas permukaan kubus yaitu:
Luas = 6 x Luas persegi
Luas = 6 x ....
Luas = 6 x ....

Luas permukaan kubus = 6 x ....

7

Figure 2. LKPD integrated with augmented reality

Figure 2 is a development of LKPD, which was created using the Canva application and integrated with augmented reality. The augmented reality in the LKPD can be seen from the cube on the purple box, which can be scanned and display animations of cube nets.

The validation results by experts show that the LKPD developed has a very high level of validity. The validation results by material experts showed that the feasibility aspect of the content obtained an average score of 87.50%, the linguistic aspect of 86.67%, and the feasibility aspect of the presentation component of 88.33%. Overall, the validation of the subject matter experts resulted in an average score of 87.56%, which is categorized as very valid. Consider the following table 4:

Table 1. Material Expert Validation Results

Assessment Indicators	Assessment Score			Total Score	P%	Average	Criterion
	Validator 1	Validator 2	Validator 3				
Content Eligibility	33	40	32	105	87,50%	87,56%	Highly Valid
Linguistics	13	14	12	39	86,67%		
Eligibility of Serving Components	17	20	16	53	88,33%		

Similarly, the results of validation by design experts showed that the writing design aspect obtained an average score of 88.33%, the content design of the LKPD of 86.67%, and the characteristics of the LKPD of 86.67%, with an overall average of 87.22%, which is also included in the very valid category. These results show that the AR-integrated LKPD has excellent quality in terms of content and design, so it is suitable for use in learning. Consider the following table 5:

Table 5. Design Expert Validation Results

Assessment Indicators	Assessment Score			Total Score	P%	Average	Criterion
	Validator 1	Validator 2	Validator 3				
Writing Design	18	19	16	53	88,33%	87,22%	Highly Valid
LKPD Content Design	26	28	24	78	86,67%		
Characteristics of LKPD	8	10	8	26	86,67%		

After the validation process, the validator team provided feedback and suggestions for improvement. The material experts recommended refining the clarity of problem-solving steps and ensuring that the mathematical terminology used was consistent with the curriculum guidelines. Meanwhile, the design expert suggested improving the visual layout to enhance readability and optimizing the placement of AR markers for better scanning accuracy. Based on these recommendations, revisions were made before proceeding to the practicality test phase, including refining the instructional content, adjusting the formatting, and repositioning some AR markers to improve usability. A practicality test was conducted to measure how educators and students could easily use the LKPD. The individual trial, which was conducted involving a grade VII mathematics teacher, resulted in an average score of 80% in the very practical category. The small group trial, involving nine learners with varying levels of ability, showed an average result of 72.30%, which was categorized as practical.

Meanwhile, the field trial, which was conducted on 22 students, produced an average score of 77.64%, which was also included in the practical category. Overall, the average score of the practicality test was 76.65%, which shows that this LKPD can be used well in mathematics learning. Consider the following table 6:

Table 2. LKPD Practicality Test Results

Practicality Trial	Total Score	P%	Criteria	Average	Criteria
Individual Test	40	88,33%	Very Practical		
Small Group Test	488	86,67%	Practical	76,65%	Practical
Field Test	1281	77,64%	Practical		

Field trials were carried out using pre-tests and post-tests to assess the improvement of student learning outcomes and measure the effectiveness of LKPD. The pre-test results showed that the student's average score was 15.18, while the post-test results increased to 64.45. Using the N-Gain formula, a value of 0.58 was obtained, which is included in the medium category. The interpretation of effectiveness based on the N-Gain score shows that this LKPD has an effectiveness level of 58%, which is included in the category of quite effective. Although it has not reached the high category, these results show that AR-based LKPD can positively impact students' learning outcomes in spatial geometry material. Consider the following table 7 below.

Table 3. Results of Effectiveness Test with N-Gain Score

Field Trial	Total Score	Average	N-Gain Skor	N-Gain Score Categories	N-Gain Percentage	Criterion
Pre-test	338	15,18				
Post-Test	1418	64,45	0,58	moderate	58%	Quite Effective
Total	1752	79,63				

The effectiveness test results in Table 7 indicate a significant improvement in students' learning outcomes after using the AR-based LKPD. The pre-test results show a total score of 338, with an average score of 15.18, which suggests that students initially had difficulty understanding spatial geometry concepts. After implementing the AR-based LKPD, the post-test results demonstrate a substantial increase, with a total score of 1418 and an average score of 64.45. The N-Gain score of 0.58 falls within the moderate category, indicating that the LKPD considerably impacts students' comprehension of the material. With an N-Gain percentage of 58%, the effectiveness of this learning tool is classified as "Quite Effective." Although the LKPD has not yet achieved a high effectiveness level, these results highlight its potential as an innovative instructional tool for improving students' spatial reasoning and mathematical literacy. Future improvements, such as enhancing interactive features and expanding AR accessibility, could further optimize its effectiveness in mathematics education.

3.2. Discussion

According to Nieveen in Rewatus et al. [30], a high-quality learning product must meet three main criteria: validity, practicality, and effectiveness. Based on the results of this study, the Augmented Reality (AR)-based Student Worksheet (LKPD) meets the first two criteria, validity and practicality, with a very good category. The validity of the LKPD is reflected in the expert validation results, with material experts scoring it at 87.56% and design experts at 87.22%. These findings align with Plomp's theory [31], which emphasizes that technology-based learning media must undergo validation to ensure content suitability and effectiveness in supporting the learning process. Furthermore, Pambudi, Buchori, and Aini [32] found that integrating technology into mathematics learning enhances students' understanding, particularly in abstract concepts such as geometry. The high validity of this LKPD suggests that its development has considered both pedagogical and technical aspects, making it a viable tool for mathematics education.

From a practical perspective, the AR-based LKPD received positive responses from teachers (80%) and students (72.30% in small group trials and 77.64% in field trials), indicating that the media is user-friendly and aligns with educational needs. These findings align with Vygotsky's [33] theory of the zone of proximal development, which highlights the importance of interactive learning tools in enhancing comprehension of complex concepts. In this context, AR acts as scaffolding that helps students grasp abstract geometric concepts through three-dimensional visualization. Additionally, a study by Adna, Ningsih, and Fitri [34] found that using AR in mathematics learning increased student participation and reduced difficulties in understanding spatial structures. Therefore, the development of this LKPD provides a solution to the challenges of mathematics instruction, which less interactive conventional methods have traditionally dominated.

However, while the effectiveness of the AR-based LKPD shows promising results, with an N-Gain score of 0.58 (moderate category), further development is needed to enhance student engagement in exploring concepts using AR. These findings are consistent with Syamiluddin's research [35], which stated that AR technology in education can increase student motivation and participation, but its effectiveness heavily depends on interaction design. Arici [36] also found that although AR improves comprehension of abstract concepts, its success depends on the quality of the learning experience provided by the technology. Therefore, developing more advanced interactive features, such as dynamic simulations and AR-based evaluation systems, is essential to maximizing the effectiveness of this LKPD in mathematics education.

Moreover, this study confirms that using AR in LKPD can overcome several challenges in mathematics learning, particularly in visualizing geometric concepts. In conventional learning, students often struggle to understand the relationship between two-dimensional and three-dimensional shapes. This finding is supported by Listiawan and Antoni [37], who state that AR-based media help students comprehend geometric transformations more effectively than text- or image-based learning. By integrating AR, students can interact with geometric objects from multiple perspectives, enabling a deeper understanding of spatial structures. This approach makes abstract concepts more tangible and fosters an interactive and engaging learning environment.

Nevertheless, several technical limitations must be considered when implementing AR-based LKPD. One major issue is the limited compatibility of AR applications, which only function on specific versions of Android devices. Additionally, the need for colour-printed markers poses a challenge for schools with limited printing facilities. This is consistent with the findings of Nurhasanah et al. [24], who discovered that AR-based learning in mathematics often faces technical constraints, such as device limitations and accessibility issues. Another challenge is a stable internet connection to access AR features optimally. In some cases, students with limited access to technology may find it difficult to use this medium effectively. Therefore, further research is recommended to develop a more flexible AR application that can function across various operating system versions and does not rely on colour printing or an internet connection.

Furthermore, the pedagogical approach in using AR-based LKPD should be explored in greater depth to ensure that it is not merely instructional but also promotes independent conceptual exploration. Project-based learning (PBL) or problem-based learning (PBL) approaches can be effective strategies for utilizing AR-based LKPD to enhance student engagement in learning. Mustaqim [19] found that integrating AR in problem-based learning can improve students' critical thinking skills, as they can directly test hypotheses and seek solutions through interactive visualization. Therefore, to optimize the effectiveness of this AR-based LKPD, further exploration of instructional strategies is necessary to fully leverage AR technology in the teaching and learning process.

4. CONCLUSION

This research produced an Android-based Augmented Reality (AR) integrated Student Worksheet (LKPD) designed to improve students' mathematics learning outcomes, especially in spatial geometry materials such as cubes, prisms, and cylinders. Based on the validation results, the LKPD developed meets the criteria of validity with a very valid category, practicality with a practical category, and effectiveness with a reasonably effective category. These findings show that AR-based learning media can be innovative in increasing student engagement and understanding of abstract mathematical concepts.

In detail, the validation results show that this LKPD has excellent quality of content and design, with a validation score of 87.56% for material experts and 87.22% for design experts. The practicality test shows that this LKPD is easy for educators and students to use, with an average score of 76.65%, which is included in the practical category. Meanwhile, the results of the effectiveness test show that this LKPD can improve student learning outcomes with an N-Gain value of 0.58, which is included in the medium category with an effectiveness rate of 58%. Although its effectiveness has not reached the high category, these results show that AR-based LKPD positively impacts mathematics learning.

Although this study shows promising results, some limitations need to be noted. First, the AR application is only compatible with Android devices version 10 and below, so its use is still limited. Second, markers in LKPD can only be scanned if they are printed in colour, which may be an obstacle for schools with limited printing facilities. Therefore, further development is needed to increase the flexibility of AR applications to be compatible with various operating system versions, as well as develop marker technology that can be recognized in black and white format.

Based on the results of this study, several recommendations can be given. First, educators can use this AR-based LKPD as an innovative teaching material in mathematics learning to increase student engagement and understanding. Second, further research is suggested to develop more complex interactive features in AR applications, such as dynamic animation simulations and augmented reality-based automated evaluation systems. Third, AR-based LKPD must be implemented on a broader scale to evaluate its impact on various levels of education and other mathematics materials. With further development, AR technology is hoped to be optimized in education as an innovative and compelling learning medium.

REFERENCES

[1] J. A. Sara and Y. Danawak, “Kajian Media Pembelajaran Augmented Reality (AR) Dalam Pembelajaran Bangun Ruang,” in *Prosiding Seminar Nasional Matematika Dan Sains*, Indramayu: Unwir, 2022, pp. 240–247. Accessed: Feb. 24, 2025. [Online]. Available: https://prosiding.biounwir.ac.id/article/view/200

[2] K. H. B. Pambudi, A. Buchori, and A. N. Aini, “Pengembangan Media Pembelajaran Berbasis Android Menggunakan Augmented Reality Pada Materi Bangun Ruang Sisi Datar,” *Jurnal Pendidikan Matematika dan Sains*, vol. 6, no. 1, pp. 61–69, 2018.

[3] T. W. Liswati, N. G. A. P. Sakinah, and Y. S. Yuniarti, *Pengembangan instrumen penilaian berbasis literasi numerasi*. Jakarta: Direktorat Sekolah Menengah Atas, 2021.

[4] OECD, “PISA 2022 Results (Volume I and II) - Country Notes: Indonesia,” https://www.oecd.org/en/publications/pisa-2022-results-volume-i-and-ii-country-notes_ed6fbcc5-en/indonesia_c2e1ae0e-en.html. Accessed: Feb. 24, 2025. [Online]. Available: https://www.oecd.org/en/publications/pisa-2022-results-volume-i-and-ii-country-notes_ed6fbcc5-en/indonesia_c2e1ae0e-en.html

[5] R. K. Wati and A. Nurcahyo, “Kemampuan Numerasi Siswa dalam Menyelesaikan Soal Geometri pada Asesmen Kompetensi Minimum,” *Jurnal Cendekia : Jurnal Pendidikan Matematika*, vol. 7, no. 2, pp. 1689–1699, Jun. 2023, doi: 10.31004/cendekia.v7i2.2380.

[6] E. P. Purba, B. Sinaga, M. Mukhtar, and E. Surya, “Analysis of the Difficulties of the Mathematical Creative Thinking Process in the Application of Problem Based Learning Model,” in *Proceedings of the 2nd Annual International Seminar on Transformative Education and Educational Leadership (AISTEEL 2017)*, Paris, France: Atlantis Press, 2017. doi: 10.2991/aisteel-17.2017.55.

[7] T. R. Puspasari, “Augmented reality-based vs digital vs text-book teaching materials in online geometry class,” *AIP Conf Proc*, vol. 2926, no. 1, 2024, doi: 10.1063/5.0183699.

[8] T. Tibyani, “Visualization of Students’ Performance from Digital Learning Media Using Self-Organizing Map (SOM),” *AIP Conf Proc*, vol. 3132, no. 1, 2024, doi: 10.1063/5.0212471.

[9] S. Utaminingsih, “Management of Mathematics Learning Based on Interactive Digital Worksheets to Improve Students’ Critical Thinking Ability,” *Journal of Curriculum and Teaching*, vol. 13, no. 1, pp. 159–169, 2024, doi: 10.5430/jct.v13n1p159.

[10] H. Nasbey, “Digital Physics Module for 21st Century Education on New and Renewable Energy Based on the Dilemma-STEAM Learning Model,” *J Phys Conf Ser*, vol. 2866, no. 1, 2024, doi: 10.1088/1742-6596/2866/1/012117.

[11] T. Nurrita, “Pengembangan Media Pembelajaran untuk Meningkatkan Hasil Belajar Siswa,” *MISYKAT: Jurnal Ilmu-ilmu Al-Quran, Hadist, Syari’ah dan Tarbiyah*, vol. 3, no. 1, p. 171, Jun. 2018, doi: 10.33511/misykat.v3n1.171.

[12] S. Ulandari, N. K. Dewi, and S. Istiningsih, “Pengembangan Alat Peraga Jari Baru (Jaring-Jaring Bangun Ruang) Berbasis Inkuiri pada Mata Pelajaran Matematika Siswa Kelas VI SDN 02 Pejanggik Praya Tengah,” *Jurnal Ilmiah Profesi Pendidikan*, vol. 7, no. 1, pp. 216–222, Mar. 2022, doi: 10.29303/jipp.v7i1.428.

[13] S. F. Adna, M. F. Ningsih, and A. Fitri, “Pengembangan Media Pembelajaran Menggunakan Mobile Aplikasi Berbasis Augmented Reality Materi Dimensi Tiga Kelas XII SMA Negeri 4 Pekalongan,” *Jurnal Karya Pendidikan Matematika*, vol. 7, no. 2, p. 32, Oct. 2020, doi: 10.26714/jkpm.7.2.2020.32-39.

[14] F. Eliza, “Android-Based Mobile Learning Application Using App Inventor on Computer Operating System Material: The Development and Validity Study,” *TEM Journal*, vol. 13, no. 1, pp. 624–634, 2024, doi: 10.18421/TEM131-65.

[15] T. Al Shloul, “Role of activity-based learning and ChatGPT on students’ performance in education,” *Computers and Education: Artificial Intelligence*, vol. 6, 2024, doi: 10.1016/j.caeai.2024.100219.

[16] F. Arici, “Investigating the Effectiveness of Augmented Reality Technology in Science Education in Terms of Environmental Literacy, Self-Regulation, and Motivation to Learn Science,” *Int J Hum Comput Interact*, vol. 40, no. 24, pp. 8476–8496, 2024, doi: 10.1080/10447318.2024.2310921.

[17] H. Budiman, “Peran Teknologi Informasi Dan Komunikasi Dalam Pendidikan,” *Al-Tadzkiyyah: Jurnal Pendidikan Islam*, vol. 8, no. 1, p. 31, Dec. 2017, doi: 10.24042/atjpi.v8i1.2095.

[18] S. Saputri and A. J. P. Sibarani, “Implementasi Augmented Reality Pada Pembelajaran Matematika Mengenal Bangun Ruang Dengan Metode Marked Based Tracking Berbasis Android,” *Komputika : Jurnal Sistem Komputer*, vol. 9, no. 1, pp. 15–24, Apr. 2020, doi: 10.34010/komputika.v9i1.2362.

[19] I. Mustaqim, “Pemanfaatan Augmented Reality Sebagai Media Pembelajaran,” *Jurnal Pendidikan Teknologi dan Kejuruan*, vol. 13, no. 2, Oct. 2016, doi: 10.23887/jptk-undiksha.v13i2.8525.

[20] T. Listiawan and A. Antoni, “Pengembangan Media Pembelajaran Matematika Berbasis Augmented Reality (AR) Pada Materi Transformasi Geometri,” *JP2M (Jurnal Pendidikan dan Pembelajaran Matematika)*, vol. 7, no. 1, pp. 43–52, Mar. 2021, doi: 10.29100/jp2m.v7i1.2099.

[21] A. M. Arifin, H. Pujiastuti, and R. Sudiana, “Pengembangan media pembelajaran STEM dengan augmented reality untuk meningkatkan kemampuan spasial matematis siswa,” *Jurnal Riset Pendidikan Matematika*, vol. 7, no. 1, pp. 59–73, Sep. 2020, doi: 10.21831/jrpm.v7i1.32135.

[22] F. Rozi, R. R. Kurniawan, and F. Sukmana, “Pengembangan Media Pembelajaran Pengenalan Bangun Ruang Berbasis Augmented Reality Pada Mata Pelajaran Matematika,” *JIPI (Jurnal Ilmiah Penelitian dan Pembelajaran Informatika)*, vol. 6, no. 2, pp. 436–447, Dec. 2021, doi: 10.29100/jipi.v6i2.2180.

[23] D. Irmayanti, L. Sri Andar Muni, and M. Pratiwi, “Rancang Bangun Aplikasi Pembelajaran Bangun Ruang Berbasis Augmented Reality,” *NUANSA INFORMATIKA*, vol. 16, no. 2, pp. 123–134, Jul. 2022, doi: 10.25134/nuansa.v16i2.6004.

[24] N. Nurhasanah, L. Hayati, N. H. Salsabila, and Amrullah, “Pengembangan Media Pembelajaran Berbasis Augmented Reality Dengan Menggunakan Pendekatan Etnomatematika Materi Bangun Ruang Sisi Datar,” *Journal of Classroom Action Research*, vol. 5, no. 4, pp. 260–266, Dec. 2023, doi: 10.29303/jcar.v5i4.5642.

[25] R. Rochmad, “Desain Model Pengembangan Perangkat Pembelajaran Matematika,” *Kreano: Jurnal Matematika Kreatif-Inovatif*, vol. 3, no. 1, pp. 59–72, 2012.

[26] S. Arikunto, *Metode peneltian*. Jakarta: Rineka Cipta , 2010.

[27] Riduwan, *Skala Pengukuran Variabel-variabel Penelitian*. Bandung: Alfabeta, 2015.

[28] I. P. I. Kusuma, N. W. S. Mahayanti, M. H. Gunawan, D. Rachman, and N. P. A. Pratiwi, “How Well Do E-portfolios Facilitate Students’ Learning Engagement in Speaking Courses during the COVID-19 Pandemic?,” *Indonesian Journal of Applied Linguistics*, vol. 11, no. 2, Sep. 2021, doi: 10.17509/ijal.v11i2.30583.

[29] A. Pratycia, A. Dharma Putra, A. G. M. Salsabila, F. I. Adha, and A. Fuadin, “Analisis Perbedaan Kurikulum 2013 dengan Kurikulum Merdeka,” *Jurnal Pendidikan Sains dan Komputer*, vol. 3, no. 01, pp. 58–64, Jan. 2023, doi: 10.47709/jpsk.v3i01.1974.

[30] A. Rewatus, S. I. Leton, A. J. Fernandez, and M. Suciati, “Pengembangan Lembar Kerja Peserta Didik Berbasis Etnomatematika Pada Materi Segitiga dan Segiempat,” *Jurnal Cendekia : Jurnal Pendidikan Matematika*, vol. 4, no. 2, pp. 645–656, Aug. 2020, doi: 10.31004/cendekia.v4i2.276.

[31] T. Plomp, N. Nieveen, A. E. Kelly, B. Bannan, and J. van den Akker, *Educational Design Research*. Enschede: Netherlands Institute for Curriculum Development, 2013.

[32] K. H. B. Pambudi, A. Buchori, and A. N. Aini, “Pengembangan Media Pembelajaran Berbasis Android Menggunakan Augmented Reality Pada Materi Bangun Ruang Sisi Datar,” 2018. [Online]. Available: https://api.semanticscholar.org/CorpusID:57975528

[33] L. Vygotsky, *Mind in Society: The Development of Higher Psychological Prosesses*. London: Harvard University Press, 1978.

[34] S. F. ’Adna, M. F. Ningsih, and A. Fitri, “Pengembangan Media Pembelajaran Menggunakan Mobile Aplikasi Berbasis Augmented Reality Materi Dimensi Tiga Kelas XII SMA Negeri 4 Pekalongan,” *Jurnal Karya Pendidikan Matematika*, vol. 7, no. 2, p. 32, Oct. 2020, doi: 10.26714/jkpm.7.2.2020.32-39.

[35] S. Syamiluddin, “Pengembangan Media Pembelajaran Augmented Reality (AR) Berbasis Android pada Materi Model Atom,” UIN Syarif Hidayatulla Jakarta, Jakarta, 2023.

[36] F. Arici, “Investigating the Effectiveness of Augmented Reality Technology in Science Education in Terms of Environmental Literacy, Self-Regulation, and Motivation to Learn Science,” *Int J Hum Comput Interact*, vol. 40, no. 24, pp. 8476–8496, Dec. 2024, doi: 10.1080/10447318.2024.2310921.

[37] T. Listiawan and A. Antoni, “Pengembangan Media Pembelajaran Matematika Berbasis Augmented Reality (AR) Pada Materi Transformasi Geometri,” *JP2M (Jurnal Pendidikan dan Pembelajaran Matematika)*, vol. 7, no. 1, pp. 43–52, Mar. 2021, doi: 10.29100/jp2m.v7i1.2099.