DEVELOPMENT AND VALIDATION OF AN AUGMENTED REALITY-ASSISTED STUDENT WORKSHEET ON THE PYTHAGOREAN THEOREM FOR MATHEMATICAL CONCEPTUAL UNDERSTANDING

Syafa Disma Syahlunda[1*], Dian Nataria Oktaviani[2] , Ahmadi[3] , Silvia Nurlutfiyani[4]

[1]*Department of Mathematics Education, Faculty of Teacher Training and Education, Pancasakti University Tegal, Tegal, Indonesia*
[2]*Department of Mathematics Education, Faculty of Teacher Training and Education, Pancasakti University Tegal, Tegal, Indonesia*

[*] *lunda8218@gmail.com*

Abstract

The limited availability of teaching materials that provide visual support and meaningful learning experiences makes it difficult for students to develop a conceptual understanding of the Pythagorean Theorem. This study aimed to develop and validate an Augmented Reality-assisted Student Worksheet (LKPD) on the Pythagorean Theorem to support students' mathematical conceptual understanding. The study employed a Research and Development (R&D) approach using the ADDIE model and was limited to the Development stage. The product was evaluated by four mathematics teachers using a validation instrument covering LKPD components, learning materials, Augmented Reality integration, mathematical conceptual understanding, didactic requirements, construction requirements, and technical requirements. The validation results showed an overall mean score of 3.88, indicating that the developed worksheet was Very Valid. The findings indicate that the integration of Augmented Reality provides clear visualization of abstract mathematical concepts and contributes to the development of valid instructional materials for junior high school mathematics learning. Therefore, the developed worksheet is considered a valid instructional material intended to support students' mathematical conceptual understanding of the Pythagorean Theorem.

Keywords: Augmented Reality; Development; Mathematical Conceptual Understanding; Student Worksheet; Validation;

1 INTRODUCTION

Mathematics is one of the fundamental subjects that plays a significant role in developing students' logical reasoning, critical thinking, and problem-solving skills. Beyond acquiring procedural knowledge, mathematics learning aims to foster students' ability to understand and apply mathematical concepts in various contexts. According to (Diana et al., 2020), mathematical conceptual understanding serves as the foundation for learning mathematical principles and theories, enabling students to connect prior knowledge with new concepts. Similarly, (Anawati, 2022) stated that students with strong conceptual understanding are able to explain mathematical ideas, identify relationships among concepts, and select appropriate procedures to solve problems. Therefore, fostering mathematical conceptual understanding has become one of the primary objectives of mathematics education, as it supports students in developing meaningful and transferable mathematical knowledge.

Despite its importance, developing students' mathematical conceptual understanding remains a persistent challenge in mathematics classrooms. Many mathematical concepts are abstract and difficult for students to visualize, causing them to rely on memorizing formulas instead of understanding the underlying concepts. (Suningsih & Maryati, 2023) reported that students' mathematical conceptual understanding is still relatively low because learning activities often fail to engage students in meaningful concept construction. Likewise, (Zenith et al., 2023) found that many students encounter difficulties in interpreting mathematical concepts and applying them to solve problems presented in different contexts. As a result, students frequently experience misconceptions and are unable to select appropriate mathematical procedures when faced with non-routine problems.

Based on an interview conducted with a mathematics teacher at SMP Negeri 3 Brebes, mathematics instruction is still predominantly supported by the MGMP companion textbook as the primary learning resource. The instructional materials mainly consist of written explanations and routine practice exercises,

providing limited opportunities for students to construct conceptual understanding independently. This situation is particularly evident in learning the Pythagorean Theorem, where many Grade VIII students experience difficulties in identifying the relationships among the sides of a right triangle and selecting appropriate mathematical procedures to solve various types of problems. Consequently, students tend to rely on memorizing formulas rather than understanding the underlying mathematical concepts. These classroom conditions indicate that the existing instructional materials have not adequately facilitated students in developing mathematical conceptual understanding and highlight the need for more interactive learning resources that support meaningful learning experiences.

Student Worksheets (Lembar Kerja Peserta Didik/LKPD) are widely used as instructional materials that facilitate students' active engagement in the learning process. Unlike conventional teaching materials that primarily provide explanations and exercises, well-designed LKPD guides students through structured learning activities that encourage them to explore concepts, construct knowledge, and solve problems independently. (Pertiwi et al., 2020) reported that meaningful learning activities incorporated into LKPD positively contribute to students' mathematical conceptual understanding. In addition, (Mailani et al., 2025) emphasized that integrating visual elements and learning activities into LKPD enhances students' participation and creates a more interactive learning environment. Therefore, developing an innovative LKPD that aligns with students' learning needs is expected to better support the development of mathematical conceptual understanding.

The integration of Augmented Reality (AR) into Student Worksheets offers an opportunity to enrich learning activities by combining structured instructional tasks with interactive visualization. AR enables virtual two-dimensional or three-dimensional objects to be displayed within real-world environments, allowing abstract mathematical concepts to be represented more concretely. According to (Firdaus et al., 2025), AR facilitates students' understanding of abstract mathematical concepts by providing interactive visual representations that are difficult to achieve through conventional instructional materials. In the context of the Pythagorean Theorem, integrating AR into LKPD can support students in visualizing the relationships among the sides of a right triangle while encouraging them to construct mathematical concepts through guided learning activities.

Several studies have explored the development of Augmented Reality-assisted instructional materials in mathematics education. (Mahsunah, 2025) developed an AR-assisted Student Worksheet and reported that the product achieved a high level of validity and practicality as a learning resource. Similarly, (Nuriyani et al., 2025) developed an AR-assisted Student Worksheet for transformation geometry and found that the product was highly valid based on expert evaluation. These studies demonstrate that integrating AR into student worksheets can improve the quality of instructional materials by providing more interactive and visually engaging learning experiences. However, the developed products were designed for different educational levels and mathematical topics, indicating that further development is needed to address the specific characteristics and learning needs of junior high school students studying the Pythagorean Theorem.

Although previous studies have demonstrated the potential of Augmented Reality-assisted Student Worksheets, research focusing on the development and expert validation of AR-assisted LKPD for the Pythagorean Theorem at the junior high school level remains limited. In particular, instructional materials that integrate interactive three-dimensional visualization into structured learning activities to support students' mathematical conceptual understanding have received relatively little attention. Therefore, this study addresses the need for an instructional material that is relevant to classroom conditions and students' learning characteristics.

The novelty of this study lies in the development of an Augmented Reality-assisted Student Worksheet on the Pythagorean Theorem using the ADDIE development model. The developed worksheet integrates interactive three-dimensional visualization into structured learning activities that are specifically designed to facilitate students' mathematical conceptual understanding. Furthermore, the developed product was evaluated through expert validation to determine its feasibility as an instructional material for junior high school mathematics learning.

Based on the identified research gap, this study addresses the following research question: How can an Augmented Reality-assisted Student Worksheet on the Pythagorean Theorem be developed and validated to support students' mathematical conceptual understanding? Accordingly, this study aims to develop and validate an Augmented Reality-assisted Student Worksheet on the Pythagorean Theorem as an alternative instructional material to support students' mathematical conceptual understanding in junior high school.

2 METHODOLOGY

This study employed a Research and Development (R&D) approach to develop and validate an Augmented Reality (AR)-assisted Student Worksheet (LKPD) on the Pythagorean Theorem for supporting students' mathematical conceptual understanding. The development process adopted the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Rayanto & Sugianti, 2020). However, this study was limited to the Development stage because the primary objective was to produce and validate a feasible learning product before wider implementation.

During the Analysis stage, a needs analysis was conducted through interviews with a mathematics teacher at SMP Negeri 3 Brebes. The analysis focused on students' learning needs, mathematical conceptual understanding, curriculum requirements, and the characteristics of the Pythagorean Theorem. The findings revealed that classroom instruction mainly relied on MGMP companion textbooks and routine exercises, while learning resources integrating interactive technology to support conceptual understanding were not yet available.

In the Design stage, the structure and content of the worksheet were prepared by determining the learning objectives, organizing learning activities, and integrating Augmented Reality into the worksheet. The AR content was created using Assembler Edu with a marker-based tracking approach. Three-dimensional learning objects were accessed by scanning QR codes embedded in the worksheet, enabling students to visualize the concepts interactively.

The Development stage involved producing the initial prototype of the AR-assisted worksheet and conducting expert validation. The developed product was evaluated by four mathematics teachers using a validation questionnaire consisting of seven aspects: LKPD components, learning materials, Augmented Reality integration, mathematical conceptual understanding, didactic requirements, construction requirements, and technical requirements. Each validation item was rated using a four-point Likert scale ranging from 1 (very poor) to 4 (very good).

The validation data were analyzed descriptively by calculating the average score of each validation indicator, followed by the overall validity score, following the procedure proposed by (Kirana & Nazihah, 2018). First, the average score of each validation indicator was calculated using the following formula:

$$\bar{V} = \frac{\sum_{i=1}^{n} x_i}{n}$$

Where $\bar{V}$ is the average score of each validation indicator, x_i is the score assigned to the i - th indicator, and n is the number of validators. The overall validity score was then calculated using the following formula:

$$\bar{x} = \frac{\sum_{i=1}^{n} \bar{V}_i}{n}$$

Where $\bar{x}$ is the overall validity score, $\bar{V}_i$ is the average score to the i - th validation indicator, and n is the total number of validation indicators. The resulting score was interpreted according to the validity criteria proposed by (Widoyoko, 2018), where a mean score of 3.25–4.00 indicates that the developed worksheet is categorized as Very Valid.

3 RESULTS

This study resulted in the development of an Augmented Reality-assisted Student Worksheet (LKPD) for learning the Pythagorean Theorem. The product was developed using the ADDIE model, which consists of the Analysis, Design, and Development stages. The research was limited to the development stage, focusing on the design, development, and validation of the proposed learning material. The results obtained from each stage of the development process are presented in the following subsections.

3.1 Analysis

The analysis stage was conducted to identify the learning conditions and determine the requirements for developing an Augmented Reality-assisted Student Worksheet (LKPD) on the Pythagorean Theorem. This stage included student needs analysis, mathematical conceptual understanding analysis, curriculum analysis, and material analysis. The results of these analyses served as the basis for designing a learning product that was relevant to students' characteristics and curriculum requirements.

3.1.1 Student Needs Analysis

The student needs analysis was conducted through interviews with a mathematics teacher at SMP Negeri 3 Brebes. The results showed that the school implements the Merdeka Curriculum and applies the discovery learning model in mathematics instruction. Learning activities were supported by concrete teaching aids and teacher-developed worksheets, which encouraged students to participate actively during classroom discussions. However, the interview revealed that Augmented Reality had never been integrated into mathematics learning. According to the teacher, students need more interactive learning media to visualize abstract mathematical concepts, particularly the Pythagorean Theorem. Therefore, an Augmented Reality-assisted LKPD was considered necessary to provide a more engaging and meaningful learning experience.

3.1.2 Analysis of Mathematical Conceptual Understanding

Based on the interview with the mathematics teacher, students generally demonstrated the ability to identify known and unknown information in mathematical problems and apply the Pythagorean Theorem to determine the length of the hypotenuse. However, students still experienced difficulties in determining the length of a leg when the hypotenuse was known, performing square and square-root operations, and solving contextual problems. These findings indicate the need for instructional materials that provide structured learning activities and interactive visualization to support students' mathematical conceptual understanding.

3.1.3 Curriculum Analysis

The curriculum analysis was conducted to ensure that the developed LKPD aligned with the Merdeka Curriculum for Grade VIII students. Based on the curriculum, students are expected to understand the relationship among the sides of a right triangle, determine unknown side lengths, apply the converse of the Pythagorean Theorem, and solve problems involving plane figures, solid figures, and real-life situations. Therefore, the learning objectives, activities, and assessments included in the LKPD were designed to achieve these curriculum outcomes while integrating Augmented Reality to enhance conceptual understanding.

3.1.4 Material Analysis

The material analysis focused on identifying the essential concepts of the Pythagorean Theorem to be included in the worksheet. The developed material covers the relationship among the sides of right triangles, determining unknown side lengths, the converse of the Pythagorean Theorem, and its applications in geometry and contextual problems. To facilitate conceptual understanding, the learning content was organized sequentially and supported by Augmented Reality visualizations. This approach enables students to observe mathematical concepts more concretely and interactively before solving related problems.

3.2 Design

The design stage focused on preparing the initial prototype of the Augmented Reality-assisted LKPD based on the findings from the analysis stage. The worksheet was designed in accordance with the Grade VIII learning outcomes of the Merdeka Curriculum and aimed to improve students' mathematical conceptual understanding of the Pythagorean Theorem. The learning activities were organized systematically to guide students from understanding basic concepts to applying them in solving mathematical and contextual problems. The LKPD consists of several components, including the cover page, learning objectives, prerequisite competencies, instructions for use, learning activities, learning materials, examples, exercises, reflection, and references. The learning activities were designed according to the Discovery Learning model and incorporated indicators of mathematical conceptual understanding, including recognizing concepts, understanding concept characteristics, identifying concepts, and solving mathematical problems. In addition, Augmented Reality was integrated into the worksheet using the Assembler Edu platform. Students accessed the AR content by scanning QR codes with their smartphones, allowing them to observe three-dimensional visualizations of the Pythagorean Theorem. The AR feature was embedded within the learning materials to support conceptual visualization, encourage active learning, and help students understand abstract mathematical concepts more effectively. Furthermore, the learning activities were specifically designed to facilitate four indicators of mathematical conceptual understanding: recognizing concepts, understanding concept characteristics, identifying concepts, and solving mathematical problems.

3.3 Development

The development stage transformed the initial design into an Augmented Reality-assisted Student Worksheet (LKPD). At this stage, the product was developed based on the design from the previous phase, validated by experts, and revised according to the validators' suggestions. The final product consists of several components, including the cover, learning objectives, instructions, learning activities, Augmented Reality integration, exercises, reflection, and references.

3.3.1 Product Development

The developed LKPD was designed to support students' conceptual understanding of the Pythagorean Theorem through interactive learning activities integrated with Augmented Reality technology. The worksheet includes a structured sequence of learning materials, examples, exercises, and QR-code-based AR visualization. The product was developed in accordance with the Merdeka Curriculum and the characteristics of Grade VIII junior high school students.

Figure 1. *Cover of the Augmented Reality-assisted LKPD.*

The cover was designed using attractive colors and mathematical illustrations related to the Pythagorean Theorem. It contains the title of the worksheet, student identity section, and visual elements representing right triangles and square relationships to introduce the learning topic. Furthermore, the LKPD integrates Augmented Reality features that enable students to visualize mathematical concepts through three-dimensional objects. Students can access the AR content by scanning the QR code provided in the worksheet using a smartphone.

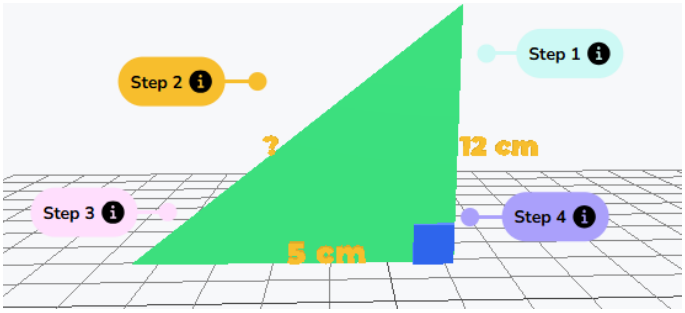

Figure 2. *Augmented Reality visualization of the Pythagorean Theorem.*

The AR visualization presents three-dimensional representations of the Pythagorean Theorem and its applications, allowing students to observe the relationship among the sides of a right triangle interactively. This feature is intended to support conceptual understanding by providing a more concrete learning experience.

3.3.2 Expert Validation

The developed LKPD was validated by four junior high school mathematics teachers to evaluate its content validity and overall feasibility before classroom implementation. The validation instrument consisted of seven assessment aspects: LKPD components, learning materials, Augmented Reality integration, mathematical conceptual understanding, didactic requirements, construction requirements, and technical

requirements. Each indicator was assessed using a four-point Likert scale, where 1 indicates "very poor" and 4 indicates "very good." The results of the expert validation are presented in Table 1.

Table 1. *Validation Results of the Developed LKPD .*

Validation Aspect	Mean Score	Category
LKPD Components	3.92	Very Valid
Learning Materials	3.83	Very Valid
LKPD and AR Integration	3.83	Very Valid
Mathematical Conceptual Understanding	3.89	Very Valid
Didactic Requirements	4.00	Very Valid
Construction Requirements	3.92	Very Valid
Technical Requirements	3.92	Very Valid
Overall Average	**3.88**	Very Valid

The validation results indicate that the developed LKPD fulfills the requirements of a valid instructional material. High scores across all assessment aspects demonstrate that the worksheet is appropriate in terms of content, instructional design, Augmented Reality integration, and technical quality. The overall validation score was **3.88**, indicating that the developed LKPD falls into the "Very Valid" category. Among the evaluated aspects, the highest score was obtained for the didactic requirements (4.00), indicating that the learning activities were well organized and supported students' conceptual understanding. The remaining aspects also achieved high scores, demonstrating that the learning materials, worksheet components, Augmented Reality integration, construction, and technical design met the expected quality standards. Therefore, the developed LKPD is considered suitable for use as a mathematics learning material on the Pythagorean Theorem. These findings are consistent with previous studies demonstrating that integrating Augmented Reality into student worksheets can improve the quality and validity of instructional materials. (Mahsunah, 2025) and (Nuriyani et al., 2025) similarly reported that AR-assisted worksheets achieved a high level of validity based on expert evaluation. The high validation score obtained in this study indicates that integrating Augmented Reality with structured learning activities can support the development of instructional materials that are pedagogically appropriate and suitable for mathematics learning, particularly for the Pythagorean Theorem.

3.3.3 Product Revision

Following the expert validation, several revisions were made based on the validators' recommendations to improve the quality and consistency of the developed LKPD. One of the major revisions involved the learning objectives in the first learning activity. Before the revision, the second learning objective was not fully aligned with the topic of the lesson. After revision, the learning objective was modified to specifically state that students are expected to determine the length of one side of a right triangle, making it more consistent with the Pythagorean Theorem learning content. The revision is illustrated in Figure 3 and Figure 4.

Figure 3. Learning objective before revision.

Figure 4. Learning objective after revision.

The revised learning objective provides a clearer alignment between the instructional objectives and the lesson content, ensuring that the developed LKPD better supports the intended learning outcomes for the Pythagorean Theorem. Overall, the revisions improved the quality and consistency of the developed LKPD before it was finalized as a valid instructional material.

4 CONCLUSIONS

This study successfully developed an Augmented Reality-assisted Student Worksheet (LKPD) for learning the Pythagorean Theorem using the ADDIE development model up to the Development stage. The product was designed based on students' learning needs, curriculum requirements, and mathematical conceptual understanding indicators. The integration of Augmented Reality provides interactive three-dimensional visualizations that support students in understanding abstract mathematical concepts. The expert validation results showed that the developed LKPD obtained an overall mean score of **3.88**, which falls into the Very Valid category. This finding indicates that the developed LKPD satisfies the required standards in terms of worksheet components, learning materials, Augmented Reality integration, mathematical conceptual understanding, didactic, construction, and technical aspects. Therefore, the developed LKPD is considered a valid instructional material for Grade VIII students and is suitable for use in mathematics learning on the Pythagorean Theorem. Future research should continue the Implementation and Evaluation stages of the ADDIE model to investigate the practicality and effectiveness of the developed LKPD in improving students' mathematical conceptual understanding.

REFERENCES

Anawati, S. (2022). Pengaruh model pembelajaran stad terhadap kemampuan pemahaman matematis pada mata kuliah persamaan diferensial. *MATH-UMB.EDU*, *10*(1). https://doi.org/10.36085/mathumbedu.v10i1.4115

Diana, P., Marethi, I., & Pamungkas, A. S. (2020). *Kemampuan Pemahaman Konsep Matematis Siswa : Ditinjau Dari Kategori Kecemasan Matematik*. *4*(1), 24–32.

Firdaus, M. F., Eviyanti, A., Azizah, N. L., & Ariyanti, N. (2025). Augmented Reality Application for Teaching 3D Shapes in Primary School. *JICTE (Journal of Information and Computer Technology Education)*, *9*(1), 11–17. https://doi.org/10.21070/jicte.v9i1.1672

Kirana, S., & Nazihah, Z. (2018). PENGEMBANGAN LEMBAR KERJA SISWA (LKS) KELAS VIII BERCIRIKAN REALISTIC MATHEMATICS EDUCATION (RME) PADA MATERI STATISTIKA. *Pi:Mathematics Education Journal*, *1*(3), 127–133. https://doi.org/https://doi.org/10.30738/trihayu.v6i3.8151

Mahsunah, N. (2025). PENGEMBANGAN LKPD BERBASIS AUGMENTED REALITY UNTUK MENINGKATKAN KETERAMPILAN BERPIKIR KRITIS PADA MATERI FOTOSINTESIS SISWA KELAS IV MI MA'ARIF ABAR-ABIR BUNGAN GRESIK. *Etheses Uin Malang*.

Mailani, E., Ritonga, A. N. R., Saragih, D. I., Kamila, N., & Sitanggang, M. A. (2025). STRATEGI MENDESAIN LKPD YANG MENARIK UNTUK MENINGKATKAN KETERLIBATAN SISWA SD DALAM PEMBELAJARAN MATEMATIKA. *Pendidikan Inovatif*, *7*(1).

Nuriyani, E., Harman, H., & Relawati, R. (2025). Pengembangan Lembar Kerja Peserta Didik (Lkpd) Berbasis Augmented Reality (Ar) Pada Materi Transformasi Geometri Di Kelas Xi Sma Attaufiq Jambi. In *PHI: Jurnal Pendidikan Matematika* (Vol. 9, Issue 1). https://doi.org/10.33087/phi.v9i1.492

Pertiwi, P., Handoko, H., & Toheri. (2020). Pengaruh penerapan meaningful learning berbantuan LKPD bertema terhadap pemahaman konsep matematika dan kemampuan metakognitif peserta didik. *Jurnal Math Educator Nusantara*, *6*(2), 128–136. https://pdfs.semanticscholar.org/53a3/ac678350d15ea7def07f876d1c09d54add6c.pdf

Rayanto, Y. H., & Sugianti. (2020). *Penelitian Pengembangan Model Addie Dan R2D2*. Pasuruan: Lembaga Academic & Research Institute.

Suningsih, T., & Maryati, I. (2023). Analisis Kemampuan Pemahaman Konsep Matematis Siswa Kelas Pada Materi Garis dan Sudut. *JPd Matematika*, *6*(2), 19–28. https://doi.org/doi: 10.35974/dm.v6i2.3133

Widoyoko. (2018). *Teknik Penyusunan Instrumen Penelitian*. Pustaka Pelajar : Yogyakarta.

Zenith, F., Sabandar, J., & Amelia, R. (2023). Analisis Kemampuan Pemahaman Matematis Siswa Kelas viii SMPN 3 Ngamprah pada Materi Relasi dan Fungsi. *JPMI: Jurnal Pembelajaran Matematika Inovatif*, *6*(4), 1619–1628. https://doi.org/doi: 10.22460/jpmi.v6i4.17565.