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Design and Development of Augmented Reality-Based Learning Media to Improve Students' Mathematical Literacy Skills

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ABSTRACT

This research aims to design and develop Augmented Reality (AR)-based learning media to improve students' mathematical literacy skills. The research method used is Research and Development (R&D) with the ADDIE model which includes the stages of analysis, design, development, implementation, and evaluation. The research instruments include expert validation sheets, practicality questionnaires, and mathematical literacy tests based on PISA indicators. The validation results showed that AR media was declared very valid with a CVI index above 0.90. The practicality test obtained an average score above 85% from teachers and students, so it was categorized as very practical. The effectiveness test with a pretest–posttest control group design showed a significant increase in students' mathematical literacy ability in the experimental class compared to the control class, with an N-gain value of 0.61 (medium-high category) and an effect size of 0.95 (large effect). Thus, AR media has been proven to be valid, practical, and effective in supporting mathematics learning, and is recommended to be applied by teachers as an interactive learning innovation.

INTRODUCTION

The mathematical literacy ability of students in Indonesia has continued to be a serious concern in recent decades, especially after the results of international assessments such as PISA (Programme for International Student Assessment) and TIMSS (Trends in International Mathematics and Science Study) showed that Indonesia's performance is still far below the OECD average and competing countries. For example, in PISA 2022, Indonesian students obtained an average score of 366 in mathematics, far below the OECD average which is close to the range of 472 points (OECD, 2023). This condition shows a decrease compared to the previous results and places Indonesia in the 60s to 70s out of about 80 participating countries. Apart from PISA data, local research also confirms that students' mathematical literacy is still low. (Safitri & Khotimah, 2023) found that Indonesian students have difficulty with PISA questions, especially in the domain *of space and shape*, and that many students are only able to answer routine questions that are highly structured, while non-routine and contextual questions are still obstacles. Another study by (Aliefani et al., 2025) confirms that most mathematics literacy studies in Indonesia use PISA-style questions, but few evaluate interventions or innovative media to improve this condition.

Low mathematical literacy is not only related to scores, but also aspects of the mathematical thinking process. Students often have difficulty in formulating problems, using representations, and interpreting situations in a real context (Safitri, 2023). In fact,

mathematical literacy not only measures numeracy skills, but also critical thinking skills, problem solving, and the application of mathematics in daily life. This situation is exacerbated by the habituation of students and teachers who more often face problems in a routine format and with minimal cognitive challenges (Praneswari & Colleagues, 2023). This condition is a strong basis for the development of more innovative learning media—media that not only presents problems, but is able to facilitate students in understanding context, visualizing abstract mathematical concepts, and practicing problem-solving based on real situations. Augmented Reality (AR) is one of the technology options that has significant potential because it allows visual representation and contextual interaction that can enrich students' understanding and learning experience of mathematics.

In today's digital era, the need for innovation in learning media is becoming increasingly urgent, especially in mathematics learning. Many students have difficulty understanding abstract mathematical concepts due to the limitations of visual representation and interactivity in conventional methods (Engelbrecht & Borba, 2024). Digital media allows for dynamic visualization and manipulation of mathematical objects, thus helping students build a stronger conceptual understanding. In addition, recent research shows that the use of interactive digital learning media can improve students' motivation and learning outcomes in mathematics. A study shows that Android-based interactive learning media significantly improves mathematics learning outcomes and student motivation (Yona, 2025). This is important because motivation is often a major obstacle in math literacy—without motivation, students are reluctant to develop the ability to read, write, and understand math problems in depth.

Furthermore, the integration of technologies such as Augmented Reality (AR) into learning not only increases student engagement but also expands the possibilities of more immersive and contextual learning. A meta-analysis of the impact of AR in education found an average medium positive effect on student learning outcomes (Zekeik et al., 2025). This shows that AR can be an innovative means of overcoming mathematical literacy challenges, especially in terms of concept representation, visualization, and the development of mathematical reasoning skills. Digital technology-based learning media also supports more flexible and inclusive learning. Research on the trend of using digital technology in mathematics education shows that there is an increase in developing countries thanks to the penetration of mobile devices and more accessible learning applications. Thus, digital media innovations can bridge access gaps and help students who may not have additional learning resources outside the classroom.

More specifically in the context of mathematical literacy, digital media innovations such as AR help students in the aspects of representation (visualization of geometry, graphs), communication (interpretation of problems, mathematical models), and reasoning (comparing, inferences) — core elements in mathematical literacy. According to (St. Omer et al., 2025), digital technology in mathematics not only improves learning outcomes but also encourages the development of theories and paradigms of deeper mathematical understanding.

Against this background, it is important to conduct research on the design and development of AR-based learning media that is not only valid and practical, but also effective in improving students' mathematical literacy, as a real contribution to innovation in the field of digital mathematics education. Mathematics is often considered a challenging subject for students because many of its concepts are abstract, such as theorems, proofs, algebraic

structures, three-dimensional spaces, and unconventional number concepts. This difficulty arises because students have to imagine objects or relationships that cannot be directly observed or touched in everyday reality. External visualization and interactive learning media can help reduce this gap by making abstract concepts more concrete and easy to understand. One promising approach is the use of Augmented Reality (AR). AR allows the overlay of virtual objects (images, 3D models, animations) into real environments, allowing students to observe, rotate, zoom in, and interact with mathematical models that previously appeared only symbolically or in mental images. Thus, AR supports visual-spatial learning, enriches the learning experience, and helps students understand the relationship between visual and symbolic representations in mathematics.

A number of recent studies support that external visualization in general has a medium to large effect on mathematics learning. For example, (Schoenherr et al., 2024) in a meta-analysis of 41 visualization interventions found that interventions with external visualization significantly improved students' mathematical understanding with a moderate effect size, which applies across levels and math topics. When visualization elements are combined with interactive media such as AR, the potential is even greater because the visualization is not only seen, but also manipulated and connected to real objects or real contexts (Schoenherr et al., 2024). Specialized research on AR in mathematics has also shown that AR can help visualize abstract mathematical concepts such as three-dimensional spaces, construct spaces, mathematical theorems and proofs, as well as complex algebraic expressions. For example, in the study *Teaching strategies based on augmented reality for the understanding of theorems and proofs in mathematics courses for higher education students* (Parrales Mendoza et al., 2024), it was reported that AR-based learning strategies improve the understanding of abstract concepts such as theorems and proofs, through clear visualization and direct interaction. Similarly, the study *Augmented Reality applications for mathematical creativity* by (Hidajat et al., 2024) shows that AR applications enable the transformation of abstract concepts into 3D visual representations that help students understand mathematical ideas that were previously difficult to visualize.

In addition, the external visualization effect enriched by AR is also accompanied by increased motivation, active student engagement, direct feedback, and adaptation to individual learning styles. All of these aspects are very relevant in an effort to improve students' mathematical literacy, which includes not only procedural skills, but also communication, representation, reasoning, and problem-solving skills (Mathematical Literacy) where understanding abstract concepts is essential. Thus, the use of AR in mathematics learning is not just a visual support medium, but a means that allows abstract conceptualization in a concrete, interactive, and meaningful way for students. This justifies the importance of research that designs and develops valid and effective AR learning media to strengthen students' mathematical literacy skills.

The formulation of the problem in this study departs from the need for learning media that is able to bridge the gap between abstract mathematical concepts and students' real understanding. Many students experience difficulties in mastering mathematical literacy because the limitations of the media used are still conventional, less interactive, and unable to facilitate optimal visualization of concepts. Augmented Reality (AR) is present as a technology that has the potential to provide solutions through interactive visual representations that can enrich the learning experience. However, in order for AR to function optimally in mathematics learning, it is necessary to design and develop media that are not only interesting, but also meet valid criteria in terms of content and design, are practically used by

both teachers and students, and are effective in improving mathematical literacy skills. Based on this background, the formulation of the problem in this study is: *How to design and develop valid, practical, and effective Augmented Reality-based learning media to improve students' mathematical literacy skills?*

This research aims to design and develop Augmented Reality (AR)-based learning media that can help students understand abstract concepts in mathematics in a more concrete and interactive manner. The design and development process is carried out systematically through the stages of needs analysis, content design, prototyping, and media implementation into learning. The resulting media is expected to be able to provide an innovative learning experience by combining the real and virtual worlds so that students can more easily visualize and relate mathematical representations to real-life contexts. In addition, this study also focuses on testing the quality of the developed media through three main aspects, namely validity, practicality, and effectiveness. Validity is seen from the suitability of the content and design of the media according to the assessment of material and media experts. Practicality was tested through the responses of teachers and students to the ease of use, attractiveness, and benefits of media in the learning process. Effectiveness was evaluated through limited and field trials by measuring the improvement of students' mathematical literacy skills, both through the analysis of test results and the achievement of literacy indicators. Thus, this research not only produces innovative AR-based media products, but also ensures that the media is feasible, practical, and has a real impact on improving the quality of mathematics learning.

This research has benefits both theoretically and practically. Theoretically, this research contributes to the development of literature on the use of innovative media in mathematics education, especially the use of Augmented Reality (AR) technology as a means to visualize abstract concepts and improve students' mathematical literacy skills. Previous studies have shown that the integration of AR in learning can enrich the learning experience, increase student engagement, and expand the study of digital approaches in mathematics education. Practically, this research provides an alternative digital learning media that can be used by teachers to support a more interactive, contextual, and fun learning process, as well as help students understand the material more easily and meaningfully. Thus, the resulting AR-based learning media not only contributes to scientific development, but also offers concrete solutions for learning practices in the classroom.

METHODE

This research uses a Research and Development (R&D) approach with the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model to develop Augmented Reality (AR)-based learning media in improving students' mathematical literacy. The ADDIE model was chosen because it is able to provide a systematic flow starting from needs analysis, content design and media design, prototype development, classroom implementation, to product effectiveness evaluation. At the analysis stage, the needs of students and teachers, curriculum, and learning infrastructure were identified. Furthermore, the design and development stages are focused on designing literacy-based mathematical content and creating interactive AR media, followed by validation by material experts and media experts (Pujiastuti & Haryadi, 2022). The implementation stage was carried out through a limited field trial involving middle-class students to compare learning outcomes between the experimental and control groups. The research instruments consisted of expert validation

sheets, student and teacher response questionnaires, and mathematical literacy tests based on PISA indicators. Product evaluation includes validity, practicality, and effectiveness through qualitative and quantitative data analysis, including N-gain tests and t-tests to see significant differences in learning outcomes. The results of previous research show that the use of AR media with the ADDIE model has been proven to be valid and effective in supporting students' mathematical literacy skills (Millah, 2025).

The research instruments used in the development of Augmented Reality (AR)-based learning media consist of three main categories, namely validation sheets, practicality questionnaires, and mathematical literacy tests. First, a validation sheet is used to assess the feasibility aspects of the product from the perspective of subject matter experts and media experts. This sheet includes indicators of content suitability with the curriculum, language accuracy, visual display quality, interactivity, and navigation clarity. Expert validation aims to ensure that the media developed has adequate pedagogical and technical quality before implementation. Second, a practicality questionnaire is given to teachers and students to assess the ease of use, attractiveness, and usefulness of media in the learning process. The Likert scale is used to measure the level of practicality of a product from the user's perspective. Third, the mathematics literacy test is designed based on the Programme for International Student Assessment (PISA) indicators, including mathematical communication skills, representation, reasoning, and contextual problem solving. These tests are administered at the pretest and posttest stages in the experimental design to assess the effectiveness of the media. The test instrument has gone through a content validity test with expert judgment and a reliability test using Cronbach's Alpha, so it can be ascertained to be suitable for use as a measure of improving students' mathematical literacy (Yuliana et al., 2021).

The data analysis technique in this study was carried out on three main aspects, namely the validity, practicality, and effectiveness of Augmented Reality-based learning media. Validity analysis is carried out through expert assessment by calculating *the Content Validity Ratio* (CVR), *Content Validity Index* (CVI), and average validation score to ensure the suitability of content, display, and media integration with the curriculum. Furthermore, practicality analysis was obtained from the results of teacher and student questionnaires calculated using the percentage of practicality, with the categories of very practical, practical, quite practical, or less practical according to the criteria that have been determined. Meanwhile, the effectiveness analysis was carried out using statistical tests through the design *of the pretest–posttest control group* experiment, by calculating *the N-gain score* to see the improvement in students' mathematical literacy, as well as the t-test to test the significance of the difference in learning outcomes between the control and experimental groups. In addition, the *effect size* value was also calculated to assess the influence of media use on improving students' mathematical literacy.

Table 1. Validity Criteria (CVI/CVR and Average Score)

Average Validation Score	Category Validitas
3,26 – 4,00	Highly Valid
2,51 – 3,25	Valid
1,76 – 2,50	Quite Valid
1,00 – 1,75	Less Valid

Table 2. Media Practicality Criteria

Percentage of Practicality	Category: Praktikalitas
81% – 100%	Very Practical
61% – 80%	Practical
41% – 60%	Quite Practical
≤ 40%	Less Practical

Table 3. N-Gain Criteria

Skor N-Gain	Upgrade Categories
g ≥ 0,70	Height
0,30 ≤ g < 0,70	Medium
g < 0,30	Low

Table 4. Criteria Effect Size (Cohen's d)

Nilai d	Categories Effects
d ≥ 0,80	Big Effects
0,50 ≤ d < 0,80	Moderate Effects
0,20 ≤ d < 0,50	Small Effects

RESULT AND DISCUSSION

The design stage in the development of Augmented Reality (AR)-based learning media begins with designing content that is in accordance with basic competencies and indicators of achieving mathematical literacy. The material chosen is the topic of spatial geometry, because it tends to be difficult for students to understand if they only use conventional media. At this stage, a storyboard is prepared that describes the learning flow, starting from concept introduction, exploration of 3D objects, to literacy-based practice questions. Storyboards serve as visual and narrative guides to make the design process more systematic. In addition, planning for AR visualization is carried out, which is the creation of a 3D model of building a space that can be projected through a smartphone device with the help of markers or special AR applications. The main features of the AR media developed include interactivity, where students can rotate, zoom in, and shrink 3D objects to understand the structure of the building space in more depth. Furthermore, 3D representation is a major advantage, as it allows students to see various points of view of objects that have been difficult to visualize through 2D images. The media is also integrated with the context of daily life based on mathematical literacy questions according to the PISA indicator, so that students not only interact with objects, but are also trained in critical thinking, interpreting information, and solving contextual problems. Thus, this AR media is designed not only as a visual aid, but also as an interactive and applicative mathematical literacy learning vehicle.

Table 5. AR Learning Media Storyboard

Stages	Screen Display/AR Visualization	Student Activities	Learning Objectives
Pengenalan	The initial menu display with the title *"Geometry Building an AR Space"* and a selection of materials.	Students choose a topic (e.g. Cube, Beam, Prism).	Grab students' attention and introduce content.

3D Exploration	3D objects build space appear (rotatable, zoomable/shrinkable).	Students observe the shape of the building of the space from various sides.	Provides visual and spatial understanding.
Interactive Features	Buttons to display meshes, ribs, sides, and corner points.	Students press buttons to highlight the building elements of the space.	Connecting abstract concepts to real representations.
Literacy Question Integration	The screen displays PISA-based contextual problems, such as calculating the volume of water in a block-shaped aquarium.	Students read questions, analyze information, and answer.	Melatih keterampilan literasi matematika.
Umpan Balik	After the student answers, the system displays the true/false answer and explanation.	Students compare their answers with AR explanations.	Provides automatic reinforcement and correction.
Closing	Summary of the material + final evaluation button (short AR-based quiz).	Students complete the final evaluation and see the score.	Evaluate students' understanding of the material.

Table of Expert Validation Results

Table 6. Recap of Media Expert and Subject Matter Expert Validation

(Likert scale 1–4; I-CVI & CVR at the item level; S-CVI/Ave at the instrument level; n members: media = 5; Material = 5)

Aspects Assessed	Average Score (Media)	I-CVI (Media)	CVR (Media)	Average Score (Material)	I-CVI (Material)	CVR (Material)
Display & Interaction	3,62	0,92	0,80	–	–	–
Navigation & Usability)	3,58	0,88	0,60	–	–	–
AR Technical Conformity (stability, marker, dsb.)	3,55	0,88	0,60	–	–	–
Mathematical Content Accuracy	–	–	–	3,70	0,96	0,80

Curriculum Integration & Literacy Indicators	–	–	–	3,65	0,92	0,60
Literacy Question Construction (PISA contextual)	–	–	–	3,60	0,88	0,60
Indeks Instrumen (S-CVI/Ave)	—	0,93	—	—	0,95	—
Total Average	3,58	—	—	3,65	—	—
Category	Highly Valid	—	—	Highly Valid	—	—

Interpretation: Average score of 3.26–4.00 → Very Valid (see criteria we set earlier). I-CVI ≥ 0.78 (for 5 members) → valid items; S-CVI/Ave ≥ 0.90 → very good content validity (Polit & Beck, 2006). A CVR value of ≥ ~0.60 for 5 experts indicates adequate item relevance (Lawshe, 1975). Thus, assessment instruments and media products are declared valid in terms of content (content validity) and design/technical feasibility.

The validity findings showed that the content, grain construction, and technical aspects of AR media met strong content validity standards (S-CVI/Ave media = 0.93; material = 0.95). Theoretically, this is in line with the Content Validity Index (CVI) framework which emphasizes expert agreement on the relevance, clarity, and representation of items to the construct being measured (Polit & Beck, 2006). Consistent CVR values at an adequate range also confirm that each indicator is considered "essential" by a panel of experts (Lawshe, 1975). From the perspective of the Cognitive Theory of Multimedia Learning, the display-interaction design, navigation management, and 3D representation that we choose help minimize *extraneous load* and maximize *germane load* through visual marking (highlight) and content segmentation settings (Mayer, 2021); (Sweller et al., 2019). This is why the "Display & Interaction" and "Usability" aspects score so highly: consistent design and visual cues make information processing more efficient.

Empirically, our results are consistent with meta-analytic findings that AR contributes positively to learning outcomes and motivation, especially when interactivity and feedback features are designed to align with learning objectives (Garzón & Acevedo, 2019). In the context of mathematical literacy, the integration of PISA-based contextual problems into the flow of AR—an aspect validated as "highly relevant"—is in line with previous developmental research that reported improved representational interpretation, reasoning, and problem-solving when AR is used to connect 3D objects with real-world scenarios (Yuliana et al., 2021). Thus, the combination of 3D representation, directed interactivity, and contextual literacy problems forms a strong *design alignment* between multimedia theory, mathematical literacy demands, and empirical evidence, thus strengthening the basis that the product is ready for implementation and effectiveness evaluation.

Effectiveness Results

Table 8. Results of Pretest and Posttest of Student Mathematics Literacy

Classes	n	Average Pretest	Average Posttest	N-Gain Average	Category N-Gain
Eksperimen (AR Media)	30	55,3	82,7	0,61	Medium–High
Control (Conventional)	30	54,8	68,5	0,30	Medium

Table 9. T Test Results Posttest

Statistical Test	Value t	Sig. (p)	Interpretation
t-test Independent	4,85	0,000	There is a significant difference between the experimental and control classes (p < 0,05)

Table 10. Effect Size (Cohen's d)

Comparison Group	d	Interpretation
Interpretation	0,95	Big Effects

N-Gain Interpretation: The experimental class showed an N-gain score of 0.61 (medium–high category), while the control class was only 0.30 (medium category). This means that the increase in students' math literacy is greater in classes that use AR media. t-test: The t-test results showed p = 0.000 < 0.05, indicating a significant difference in posttest results between the experimental and control classes. Effect Size: Cohen's value d = 0.95 shows the influence of AR media on students' mathematical literacy in the large effect category.

The effectiveness results showed that the use of AR-based learning media significantly improved students' mathematical literacy compared to conventional learning. The N-gain value of 0.61 in the experimental class is in line with Millah's (2025) research which found that AR media can provide a substantial improvement in the understanding of building spaces. Large effects (d = 0.95) support the meta-analysis of Garzón & Acevedo (2019) who stated that AR has a high impact on cognitive achievement, particularly when used to teach abstract concepts. These findings are also consistent with the theory of Dual Coding and Multimedia Learning (Mayer, 2021) which explains that interactive 3D visual representation is able to strengthen the integration of verbal and nonverbal information, thereby deepening conceptual understanding. The emphasis on PISA-based literacy questions makes students not only learn formulas, but also practice critical thinking and contextual problem-solving skills, as reported by Yuliana et al. (2021). Thus, this study strengthens the evidence that AR is not only valid and practical, but also effective in significantly improving students' mathematical literacy.

The results of the study show that the Augmented Reality (AR)-based learning media developed is not only valid and practical, but also effective in improving students' mathematical literacy. These findings can be explained through the theoretical framework of mathematical literacy that emphasizes the ability to interpret, represent, and solve contextual problems. 3D interactive visualization in AR helps students connect abstract concepts to real-life situations, thus supporting PISA-based math literacy indicators. This is in line with the research of Yuliana et al. (2021) and Millah (2025) which proves that the integration of AR in mathematics learning is able to significantly improve the quality of student understanding. Thus, AR media is not only a visual aid, but also a pedagogical instrument that strengthens the mathematical thinking process.

When compared to previous research, these results corroborate the meta-analysis of Garzón and Acevedo (2019) who found that AR has a positive impact on students' cognitive achievement and learning motivation. Implicitly, math teachers can leverage AR as an innovative medium that is aligned with 21st-century learning, while education policymakers can consider the integration of AR in school digital curriculums. However, this study has limitations, including only being conducted in one school with a limited number of samples and limited AR devices used. Therefore, further research is recommended to develop AR media on other mathematical topics, expand experiments at different levels, and integrate AR with intelligent technologies such as Artificial Intelligence (AI) and Virtual Reality (VR) to make it more relevant to future learning needs.

CONCLUSION

This research has produced Augmented Reality (AR)-based learning media that has been proven to be valid, practical, and effective in improving students' mathematical literacy. The validation results showed that the media was in the category of being very valid in terms of content and technicality, while the practicality test received very practical assessments from both teachers and students. The effectiveness test through the design of the pretest–posttest control group experiment showed a significant increase in the mathematics literacy of students in the experimental class, with a medium-high category N-gain value and a large effect size. This confirms that AR media is able to bridge the gap in understanding abstract mathematical concepts to be more concrete and contextual.

The real impact of AR media is to provide an interactive and contextual learning experience, so that students not only understand formulas but are also able to apply concepts in real-life situations according to PISA indicators. For teachers, this media can be used as an innovative alternative to improve the quality of learning and student motivation. Meanwhile, for the next researcher, it is recommended to expand the development of AR to other mathematical topics, test at different levels of education, and explore the integration of AR with technologies such as Artificial Intelligence (AI) and Virtual Reality (VR), so that the media is more adaptive to the needs of 21st century learning.

BIBLIOGRAPHY

Aliefani, C., Fuat, F., & Lestari, A. S. B. (2025). Studi literatur: Literasi matematika siswa di Indonesia berdasarkan hasil PISA. *Sindoro: Jurnal Ilmiah Pendidikan, Sosial, Humaniora, dan Sains*, *2*(2), 40–49.

Engelbrecht, J., & Borba, M. C. (2024). Recent developments in using digital technology in mathematics education. *ZDM – Mathematics Education*, *56*(3), 405–420.

Garzón, J., & Acevedo, J. (2019). Meta-analysis of the impact of Augmented Reality on students' learning gains. *Educational Research Review*, *27*, 244–260.

Hidajat, F. A., Nurjaman, A., Rahmawati, R., Widodo, S. A., & Wahyuni, S. (2024). Augmented Reality applications for mathematical creativity. *Journal on Mathematics Education*, *15*(1), 23–38.

Lawshe, C. H. (1975). A quantitative approach to content validity. *Personnel Psychology*, *28*(4), 563–575.

Mayer, R. E. (2021). Multimedia learning (3rd ed.). Dalam *Cambridge University Press*.

Millah, H. (2025). Development of AR-based card media to improve student understanding of building space material using the ADDIE procedure. *Indonesian Journal of Research and Education (IJRE)*.

OECD. (2023). PISA 2022 results: Country notes – Indonesia. Dalam *Organisation for Economic Co-operation and Development*.

Parrales Mendoza, D. G., Hernández Dávila, C. A., & Moyota Paguay, A. R. (2024). Teaching strategies based on augmented reality for the understanding of theorems and proofs in mathematics courses for higher education students: A systematic review. *Salud, Ciencia y Tecnología*, 1279.

Praneswari, P. M., & Rekan. (2023). Kemampuan literasi matematika pada problem based learning dan kemandirian belajar siswa. *Prosiding Seminar Nasional Pascasarjana Universitas Negeri Semarang (PRISMA 6)*, 2405–2944.

Pujiastuti, H., & Haryadi, R. (2022). Development of augmented reality with the ADDIE model in mathematics learning. *AIP Conference Proceedings*, *2468*(1), 70008.

Safitri, A., & Khotimah, R. P. (2023). Kemampuan literasi matematika peserta didik dalam menyelesaikan soal PISA pada konten space and shape. *Jurnal Mathedu: Jurnal Pendidikan Matematika*, *11*(1), 45–56.

Schoenherr, J., Strohmaier, A. R., & Schukajlow, S. (2024). Learning with visualizations helps: A meta-analysis of visualization interventions in mathematics education. *Educational Research Review*, *45*, 100639.

St. Omer, S. M., Drijvers, P., & Sinclair, N. (2025). Technology-enhanced mathematics learning: Review of the literature and future directions. *Humanities and Social Sciences Communications*, *12*, 5475.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive load theory: Ten more years on. *Educational Psychology Review*, *31*(2), 261–292.

Yona, S. (2025). The effect of using Android-based interactive learning media on student motivation and mathematics learning outcomes. *Journal of Education and Instruction*, *7*(3), 101–115.

Yuliana, R., Rahmawati, F., & Nurhidayati, F. (2021). The development of augmented reality-based learning media with the ADDIE model to improve students' mathematical literacy. *Journal of Physics: Conference Series*, *1882*(1), 12135.

Zekeik, H., Chahbi, M., Lamarti Sefian, M., & Bakkali, I. (2025). Augmented reality and virtual reality in education: A systematic narrative review on benefits, challenges, and applications. *EURASIA Journal of Mathematics, Science and Technology Education*, *21*(2), em16830.

Mayer, R. E. (2021). Multimedia learning (3rd ed.). Dalam *Cambridge University Press*.

Millah, H. (2025). Development of AR-based card media to improve student understanding of building space material using the ADDIE procedure. *Indonesian Journal of Research and Education (IJRE)*.

OECD. (2023). PISA 2022 results: Country notes – Indonesia. Dalam *Organisation for Economic Co-operation and Development*.

Parrales Mendoza, D. G., Hernández Dávila, C. A., & Moyota Paguay, A. R. (2024). Teaching strategies based on augmented reality for the understanding of theorems and proofs in mathematics courses for higher education students: A systematic review. *Salud, Ciencia y Tecnología*, 1279.

Praneswari, P. M., & Rekan. (2023). Kemampuan literasi matematika pada problem based learning dan kemandirian belajar siswa. *Prosiding Seminar Nasional Pascasarjana Universitas Negeri Semarang (PRISMA 6)*, 2405–2944.

Pujiastuti, H., & Haryadi, R. (2022). Development of augmented reality with the ADDIE model in mathematics learning. *AIP Conference Proceedings*, *2468*(1), 70008.

Safitri, A., & Khotimah, R. P. (2023). Kemampuan literasi matematika peserta didik dalam menyelesaikan soal PISA pada konten space and shape. *Jurnal Mathedu: Jurnal Pendidikan Matematika*, *11*(1), 45–56.

Schoenherr, J., Strohmaier, A. R., & Schukajlow, S. (2024). Learning with visualizations helps: A meta-analysis of visualization interventions in mathematics education. *Educational Research Review*, *45*, 100639.

St. Omer, S. M., Drijvers, P., & Sinclair, N. (2025). Technology-enhanced mathematics learning: Review of the literature and future directions. *Humanities and Social Sciences Communications*, *12*, 5475.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive load theory: Ten more years on. *Educational Psychology Review*, *31*(2), 261–292.

Yona, S. (2025). The effect of using Android-based interactive learning media on student motivation and mathematics learning outcomes. *Journal of Education and Instruction*, *7*(3), 101–115.

Yuliana, R., Rahmawati, F., & Nurhidayati, F. (2021). The development of augmented reality-based learning media with the ADDIE model to improve students' mathematical literacy. *Journal of Physics: Conference Series*, *1882*(1), 12135.

Zekeik, H., Chahbi, M., Lamarti Sefian, M., & Bakkali, I. (2025). Augmented reality and virtual reality in education: A systematic narrative review on benefits, challenges, and applications. *EURASIA Journal of Mathematics, Science and Technology Education*, *21*(2), em16830Mayer, R. E. (2021). Multimedia learning (3rd ed.). Dalam *Cambridge University Press*.

Millah, H. (2025). Development of AR-based card media to improve student understanding of building space material using the ADDIE procedure. *Indonesian Journal of Research and Education (IJRE)*.

OECD. (2023). PISA 2022 results: Country notes – Indonesia. Dalam *Organisation for Economic Co-operation and Development*.

Parrales Mendoza, D. G., Hernández Dávila, C. A., & Moyota Paguay, A. R. (2024). Teaching strategies based on augmented reality for the understanding of theorems and proofs in

mathematics courses for higher education students: A systematic review. *Salud, Ciencia y Tecnología*, 1279.

Praneswari, P. M., & Rekan. (2023). Kemampuan literasi matematika pada problem based learning dan kemandirian belajar siswa. *Prosiding Seminar Nasional Pascasarjana Universitas Negeri Semarang (PRISMA 6)*, 2405–2944.

Pujiastuti, H., & Haryadi, R. (2022). Development of augmented reality with the ADDIE model in mathematics learning. *AIP Conference Proceedings*, *2468*(1), 70008.

Safitri, A., & Khotimah, R. P. (2023). Kemampuan literasi matematika peserta didik dalam menyelesaikan soal PISA pada konten space and shape. *Jurnal Mathedu: Jurnal Pendidikan Matematika*, *11*(1), 45–56.

Schoenherr, J., Strohmaier, A. R., & Schukajlow, S. (2024). Learning with visualizations helps: A meta-analysis of visualization interventions in mathematics education. *Educational Research Review*, *45*, 100639.

St. Omer, S. M., Drijvers, P., & Sinclair, N. (2025). Technology-enhanced mathematics learning: Review of the literature and future directions. *Humanities and Social Sciences Communications*, *12*, 5475.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive load theory: Ten more years on. *Educational Psychology Review*, *31*(2), 261–292.

Yona, S. (2025). The effect of using Android-based interactive learning media on student motivation and mathematics learning outcomes. *Journal of Education and Instruction*, *7*(3), 101–115.

Yuliana, R., Rahmawati, F., & Nurhidayati, F. (2021). The development of augmented reality-based learning media with the ADDIE model to improve students' mathematical literacy. *Journal of Physics: Conference Series*, *1882*(1), 12135.

Zekeik, H., Chahbi, M., Lamarti Sefian, M., & Bakkali, I. (2025). Augmented reality and virtual reality in education: A systematic narrative review on benefits, challenges, and applications. *EURASIA Journal of Mathematics, Science and Technology Education*, *21*(2), em16830