SYNERGY OF AUGMENTED REALITY AND DEEP LEARNING IN TRANSFORMING SENIOR HIGH SCHOOL STUDENTS' MATHEMATICAL LITERACY

Masdelima Azizah Sormin[1]*, Dwi Priyo Utomo[2], Elly Purwanti[3]

[1]Postdoctoral Education, Universitas Muhammadiyah Malang
[23]Universitas Muhammadiyah Malang, Indonesia
masdelima@webmail.umm.ac.id
dwi.priyo.umm@gmail.com
ellypurwanti1961@gmail.com

Abstract: *The low mathematical literacy of senior high school students, particularly in modeling and conceptual reasoning, is a major challenge in 21st-century learning. This study aims to transform mathematical literacy through the synergy of Augmented Reality (AR) and deep learning in the topic of Systems of Linear Equations in Two Variables (SPLDV). This two-cycle Classroom Action Research (CAR) involved 33 tenth-grade students from SMA Negeri 1 Angkola Selatan. Instruments included mathematical literacy tests, student activity observation sheets, and teacher performance observation sheets. Success was determined by classical mastery ≥75% (individual minimum mastery score of 75), student activity ≥80%, and teacher performance ≥80%. The results showed significant improvement from Cycle I to Cycle II: classical mastery jumped from 48.48% (mean 69.24) to 84.84% (mean 80.54); student activity shifted from predominantly moderate/low criteria to high criteria with no low criteria; teacher performance reached excellent category; and positive student responses increased dramatically from 12.12% to 84.85% in the high category. Theoretical synthesis confirms that AR reduces cognitive load, completes the experiential learning cycle, and fulfills ARCS motivation aspects, thereby optimizing the three pillars of deep learning (meaningful learning, critical thinking, creative problem solving). The synergy of AR and deep learning is proven effective in transforming students' mathematical literacy from procedural memorization toward high-level conceptual reasoning.*

Keywords: *Augmented Reality, deep learning, mathematical literacy, SPLDV*

Introduction

21st-century education demands mastery of mathematical literacy, defined as an individual's capacity to formulate, apply, and interpret mathematics in various contexts (Amaliya & Fathurohman, 2022; Ayunis & Dorisno, 2022). This ability plays a significant role in enhancing technological skills (Chasanah et al., 2020; Eka Saputri, 2023; Rahmasari & Setyaningsih, 2023) and includes reasoning and using mathematical concepts to explain and predict phenomena (Madyaratri et al., 2019).

However, observations at SMA Negeri 1 Angkola Selatan indicated symptoms of low mathematical literacy: 65% of the 33 tenth-grade students struggled with story problems requiring mathematical modeling; nearly 70% gave up on non-routine (HOTS) problems; and only 30% could explain the solution steps logically. This suggests that learning still focuses on memorizing procedures without emphasizing conceptual understanding and real-world application.

This low literacy is a serious challenge, including from the OECD's global perspective. Students' difficulties reflect abilities below PISA level 2, such as in problem-solving and logical thinking (Johar, 2022; Yulianto et al., 2024; Zahrah, 2024). Therefore, systematic learning is needed to build students' understanding and reasoning abilities (Madyaratri et al., 2019). Effective learning must be contextual, student-centered, and encourage active engagement, one of which is through deep learning that focuses on students taking turns answering questions until a target of correctness is achieved (Herwanto, 2020; Madyaratri et al., 2019).

In the modern context, Augmented Reality (AR) emerges as a promising medium to concretize abstract concepts. AR allows students to manipulate 3D geometric objects and visualize problems directly in their environment (Ardani & Fitriyah, 2023; Qorimah & Sutama, 2022; Thahir & Kamaruddin, 2021). The high interactivity of AR can create immersive learning experiences and build deep conceptual understanding, which is the foundation of mathematical literacy. However, AR's effectiveness highly depends on the learning design that integrates it meaningfully into instructional goals.

The research gap lies in the minimal integration between Augmented Reality media and the collaborative, phased approach of deep learning in efforts to improve mathematical literacy. So far, studies on AR have mostly focused on technology and visualization aspects separately, while research on deep learning in mathematics is generally conducted without the support of media capable of concretizing abstract concepts in real-time. Consequently, there is no pedagogical framework that systematically combines AR's strength in spatial visualization with deep learning mechanisms that encourage phased reasoning, conceptual understanding, and collective student responsibility.

The novelty of this research is the development of a synergy between Augmented Reality media and the Deep Learning approach as an integrated strategy to transform high school students' mathematical literacy. This novelty includes: (1) a learning design that utilizes AR as a conceptual bridge to break down non-routine problems into visual stages accessible to students deeply and continuously, (2) an AR-assisted deep learning mechanism that allows each student to be responsible for one aspect of mathematical reasoning before proceeding to the next stage of understanding, and (3) an integration model that specifically targets the improvement of mathematical literacy skills from lower PISA levels towards functional reasoning levels, which has never been designed in the context of high school mathematics learning in Indonesia. Thus, this synergy is expected not only to improve learning outcomes but also to transform the learning paradigm from procedural rote learning to deep and applicative conceptual understanding.

Method

Learning success was determined by three indicators:

1. Improvement in students' mathematical literacy skills, evidenced by at least 75% of students achieving the Minimum Mastery Criteria (KKM) of 75.
2. Improvement in student learning activities, reaching at least 80% on the student observation sheet.
3. Improvement in teacher performance, reaching at least 80% on the teacher performance observation sheet through the application of the deep learning approach.

Results and Discussion

This Classroom Action Research (CAR) was designed in two cycles, each consisting of planning, implementation, observation, and reflection. Each cycle was conducted over two meetings. Data collection instruments included mathematical literacy tests, student activity observation sheets, and teacher ability observation sheets. Success was determined based on an individual Minimum Mastery Criteria (KKM) of 75 and classical mastery of 75%.

The deep learning approach integrated with Augmented Reality (AR) in this study emphasized three main pillars: (1) meaningful learning, (2) critical thinking, and (3) creative problem solving. AR acted as a bridge for the concrete representation of the abstract concept of SLETV.

Description and Reflection of Cycle I

Mathematical Literacy Test Results

Out of 33 students, only 16 students (48.48%) achieved mastery (≥75), with a class average of 69.24.

Table 1. Distribution of Mathematical Literacy Test Results Cycle I

Interval	Number	Percentage	Category
90-100	0	0%	Very High
80-89	6	18.18%	High
65-79	16	48.48%	Moderate
55-64	11	33.33%	Low
0-54	0	0%	Very Low

Most students were still at the literal and basic application level in mathematical literacy, not yet reaching the level of reasoning and symbolic representation. Please refer to Diagram 1 for further details.

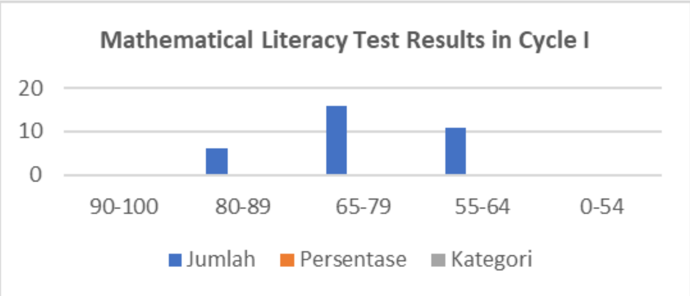

Diagram 1. Mathematical Literacy Test Results in Cycle I

Observation of Student Activities

Out of 10 aspects of mathematical literacy, 6 aspects had "Moderate" criteria (15-18 active students), and 4 aspects had "Low" criteria (10-11 active students). Indicators such as interpreting graphs, connecting representations, and formulating conjectures were still very weak. Please refer to Table 2 for further details.

Table 2. Results of Student Activity Observation Cycle I

Criteria	Number of Aspects	Aspect Numbers
High (22-27 students)	0	-
Moderate (15-21 students)	6 aspects	1, 2, 5, 7, 8, 10
Low (8-14 students)	4 aspects	3, 4, 6, 9
Very Low (0-7 students)	0	-

Based on these data, the conclusion was that improvement was needed in the next cycle through structured guidance, AR symbolic-visual connection tables, probing questions, and role assignment (spokesperson, note-taker, AR operator, conjecture checker). This effort aimed to strengthen students' understanding of line intersection points collaboratively and deeply.

Observation of Teacher Ability

The teacher was good enough in mastering the material but weak in: initial motivation, classroom management, providing space for student expression, and reflective closing. The recapitulation of the Cycle I teacher ability scores is as follows:

Table 3. Results of Teacher Ability Observation Cycle I

Aspect Group	Average Score	Category
Preliminary Activities	3.33	Adequate
Core Activities	3.36	Adequate
Closing Activities	2.00	Poor
Supporting Aspects	4.00	Good
Overall Average	**3.29**	**Adequate**

Reflection

Obstacles: noise, unclear discussion flow, group dynamics. Improvement plan:

- Strengthening visual AR scaffolding before discussion.
- Classroom management with role assignment in groups.
- Focusing on critical thinking aspects through open-ended questions.

Description and Success of Cycle II

Mathematical Literacy Test

Classical mastery reached 84.84% (28 out of 33 students), with a class average of 80.54. This is shown in Table 4.

Table 4. Distribution of Mathematical Literacy Test Scores Cycle II

Interval	Number	Percentage	Category
90-100	5	15.15%	Very High
80-89	15	45.45%	High
65-79	13	39.39%	Moderate
55-64	0	0%	Poor
0-54	0	0%	Very Poor

The "Low" category disappeared, and the "Very High" category emerged. Students were able to perform analysis, synthesis, and evaluation of contextual SLETV problems. Please refer to Diagram 2 for further details.

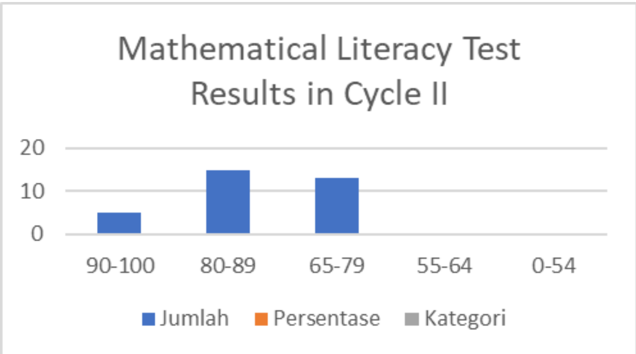

Diagram 2. Mathematical Literacy Test Results in Cycle II

(Description: A bar chart showing 5 students in Very High, 15 in High, 13 in Moderate, 0 in Low, and 0 in Very Low)

Student Activities

6 aspects had "High" criteria (22-32 active students), 4 aspects had "Moderate", and there was no "Low". Indicators for creating mathematical models, explaining strategies, and providing arguments increased dramatically. The recapitulation of Cycle II student activity observation results is shown in Table 5.

Table 5. Results of Student Activity Observation Cycle II

Criteria	Number of Aspects	Percentage
High (22-32 students)	6 aspects	60%
Moderate (11-21 students)	4 aspects	40%
Low (0-10 students)	0 aspects	0%

Teacher Ability Cycle II

The teacher achieved perfect scores (5) in: material mastery, clarity of presentation, giving assessments, and managing reflective discussions. The results obtained are shown in Table 6.

Table 6. Results of Teacher Ability Observation Cycle II

No.	Component	Total Score	Max Score	Percentage	Category
A	Introduction	14	15	93.33%	Very Good
B.1	Material Mastery	15	15	100%	Very Good
B.2	Clarity of Presentation	15	15	100%	Very Good
B.3	Deep Learning Application	15	15	100%	Very Good
B.4	Reflective Discussion Management	25	25	100%	Very Good
B.5	Giving Assessment	15	15	100%	Very Good
C	Closing	14	15	93.33%	Very Good
Total		**113**	**115**	**98.26%**	**Very Good**

Overall, the teacher's ability to implement the synergy of AR and deep learning achieved the Very Good category with a percentage of 98.26%, exceeding the success indicator (≥80%).

Discussion

Theoretical Basis of AR and Deep Learning Synergy

Deep Learning Pillar	Role of AR	Evidence in Cycle
Meaningful Learning	AR transforms abstract symbols (SLETV) into explorable 3D objects, creating a personal connection with the concept.	Cycle II: students enthusiastic about "seeing" the intersection point of two lines in real space.
Critical Thinking	AR provides multiple representations (tables, graphs, animations) that prompt students to compare and evaluate the correctness of solutions.	Increased interpretation and argumentation ability from 11 students (Cycle I) to 0 students in the low category in Cycle II.
Creative Problem Solving	Students can manipulate SLETV parameters interactively through AR, trying various possible solutions	Emergence of the "Very High" category (15.15%) in Cycle II, which did not exist before.

Deep Learning Pillar	Role of AR	Evidence in Cycle
	without fear of making mistakes.	

Cognitive Mechanism: Cognitive Load Theory (Sweller, 1988)

According to Sweller (1988), abstract mathematics learning often creates high intrinsic cognitive load. AR functions as an external representation that reduces extraneous cognitive load, allowing students' working memory capacity to focus on deep learning processes (analysis, evaluation, creation). This explains why, in Cycle II, after optimal AR scaffolding, students could achieve higher-order thinking levels.

Based on Kolb's theory, Augmented Reality (AR) supports the entire learning cycle comprehensively, especially complementing the concrete experience and reflective observation stages, which are weak in traditional mathematics. AR allows students to see objects directly, observe graph changes, infer SLETV rules, and then test strategies on new problems.

The application of ARCS motivation theory with AR media proved effective in increasing learning motivation. The components of attention, relevance, confidence, and satisfaction were fulfilled through 3D visualization, real contexts, direct manipulation, and visual feedback. The surge in the percentage of high motivation from 12.12% (Cycle I) to 84.85% (Cycle II) confirms this significant increase.

Conclusion

The synergy of AR and deep learning has proven effective in transforming high school students' mathematical literacy. AR bridges abstraction, while deep learning utilizes visualization and interactivity. Both create a virtuous cycle that increases motivation and understanding. The increase in mastery from 48.48% to 84.84% and the very positive response affirms AR as a transformational catalyst.

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