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Integrating augmented reality and local wisdom in teaching exponents: A strategy to improve students' mathematical literacy

Samuel Igo Leton[1*], Meryani Lakapu[1], Yohanes Ovaritus Jagom[1], Kristoforus Djawa Djong[1], Wilfridus Beda Nuba Dosinaeng[2], Dianne Amor Kusuma[3]
[1]Department of Mathematics Education, Universitas Katolik Widya Mandira, East Nusa Tenggara, Indonesia
[2]Department of Mathematics Education, The University of Queenslnad, Queensland, Australia
[3]Department of Mathematics, Universitas Padjadjaran, West Java, Indonesia
[*]Correspondence: letonsamuel@unwira.ac.id

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Abstract

Developing mathematical literacy in exponent learning requires students to connect authentic experiences, representations, and mathematical ideas. This study developed and evaluated Augmented Reality (AR)-enhanced instructional materials using local wisdom as an authentic context and AR as a pedagogical mediator. A Research and Development design following the ADDIE model was employed. The materials were validated by 11 mathematics teachers, and the literacy assessment was reviewed by two teachers. A limited implementation involved 72 eighth-grade students from two junior secondary schools in Kupang, Indonesia. Data were collected through validation sheets, questionnaires, observations, and pretest–posttest assessments. Mean validation scores were 3.55 out of 4.00 for content, 3.60 for media, and 3.25 for the assessment instrument. Student and teacher practicality scores were 81.10% and 96%, respectively. Students' mean mathematical literacy score increased from 58.72 (SD = 12.64) to 82.57 (SD = 11.80), $t(71) = 20.63$, $p < 0.001$, with a very large within-group effect size (Cohen's $d_z = 2.43$) and a moderate N-gain of 0.60. These findings indicate that integrating local wisdom and AR offers a valid, practical, and promising pedagogical mechanism for supporting mathematical literacy in exponent learning.

Keywords:
Augmented reality, Local wisdom, Mathematical literacy, Teaching materials

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1. INTRODUCTION

The development of twenty-first-century mathematics education has shifted the orientation of learning from the mastery of concepts and procedures toward the ability to use mathematics meaningfully in understanding and resolving real-life problems. Within this paradigm, mathematical literacy is regarded as a competency that enables individuals to formulate, employ, and interpret mathematics across diverse contexts through mathematical reasoning, as conceptualized in the framework of the Programme for International Student Assessment (PISA) (OECD, 2023; Wijaya et al., 2024). Although this framework has become a primary reference in mathematics education across numerous countries, the development of mathematical literacy in Indonesia continues to face significant challenges. Evidence from various international assessments consistently indicates that many students still encounter difficulties in formulating problems, applying mathematical concepts appropriately, and interpreting results across different real-life contexts. This condition suggests that low mathematical literacy cannot be addressed merely through procedural proficiency; rather, students need sustained opportunities to formulate, apply, and interpret mathematics in meaningful real-life contexts (Kappassova et al., 2025; Wijaya et al., 2015). Conversely, learning that connects mathematical concepts with contexts that are closely related to students' lived experiences has been shown to more effectively support the construction of mathematical meaning while simultaneously fostering the development of mathematical literacy (Leton et al., 2025). Accordingly, there is a pressing need for learning experiences that are contextual, meaningful, and capable of facilitating the construction of conceptual understanding, particularly in mathematical content areas that demand deep reasoning and representational thinking.

As one of the competencies that demands the ability to reason, represent, and interpret concepts meaningfully, mathematical literacy requires a learning context capable of facilitating the development of such competencies. In this regard, exponents constitute one of the particularly relevant topics, as they serve as the foundation for various advanced subjects, such as exponential and logarithmic functions, while simultaneously requiring strong conceptual understanding. Success in learning exponents is not solely determined by the ability to apply operational rules, but also by the capacity to comprehend the relationships among concepts, interpret the properties of exponents, and employ various mathematical representations consistently. This perspective aligns with the notion of relational understanding (Skemp, 1978), which underscores the importance of understanding the interconnections among concepts, and is further supported by the concept image framework proposed by Tall and Vinner (1981), which posits that the quality of understanding depends on the degree of connection between students' mental representations and the formal definition of a concept. Consistent with this theoretical foundation, numerous studies have demonstrated that students are generally capable of applying procedural rules for operations involving exponents, yet continue to encounter difficulties in articulating the mathematical reasoning underlying those procedures, connecting the properties of exponents at a conceptual level, and employing mathematical representations flexibly (Kusumanegara et al., 2024; Sevgi & Akdemir Kabalcı, 2026). Therefore, the teaching and learning of exponents necessitates learning experiences that enable students to construct mathematical meaning through contexts that are closely related to their prior experiences before progressing toward formal mathematical representations.

The demand for more meaningful learning experiences requires mathematics instruction to present authentic contexts that enable students to connect mathematical concepts with experiences that are familiar to them. From this perspective, local wisdom holds considerable potential as a pedagogical context, as it provides cultural practices, knowledge, and activities that are closely related to students' lives and can serve as a starting point for the process of mathematical meaning-making. This view is consistent with the principles of Realistic Mathematics Education, which positions meaningful context as the starting point of the mathematization process from real-world situations toward formal mathematical representations (Freudenthal, 1973), and is further reinforced by the ethnomathematics perspective, which regards cultural activities as a relevant source of mathematical knowledge for learning (D'Ambrosio, 1985). A growing body of recent research also demonstrates that the integration of local wisdom into mathematics learning contributes to improvements in conceptual understanding, mathematical reasoning, representation, and mathematical literacy through the interconnection between mathematical concepts and students' prior experiences (Iffah et al., 2025; Pratama & Yelken, 2024; Setianingsih et al., 2026). Accordingly, the primary strength of local wisdom lies not in the introduction of culture as a learning objective in itself, but rather in its capacity to provide authentic contexts that facilitate the process of mathematical meaning-making. Nevertheless, in order for such authentic contexts to be presented effectively, particularly in relation to abstract concepts such as exponents, learning media capable of bridging contextual experience with formal mathematical representations are required.

As an authentic context, local wisdom provides a foundation for students to construct mathematical meaning through experiences that are closely connected to their everyday lives. In order for this process to progress toward formal mathematical representations, particularly in relation to abstract concepts such as exponents, learning media capable of mediating visualization and learning interaction are required. One medium that holds considerable potential to fulfill this function is Augmented Reality, which operates as a pedagogical mediator bridging contextual experience with formal mathematical representations through visualization and interaction. This role is consistent with Multimedia Learning theory, which posits that learning becomes more effective when verbal and visual information are processed in an integrated manner, thereby assisting students in constructing mental representations of the concepts being studied (Mayer, 2020). From a psychological perspective, Augmented Reality can support mathematics learning by connecting physical manipulation, interactive visualization, and symbolic representations (Bujak et al., 2013). Systematic review and meta-analytic evidence further indicates that Augmented Reality can positively influence students' attitudes, motivation, spatial ability, and mathematics achievement (Flavin et al., 2025; İslim et al., 2024). Its application is also not limited to geometry, but has been extended to probability and other concepts requiring abstract mathematical representation (Cai et al., 2019; Schutera et al., 2021). Accordingly, the potential of integrating local wisdom and Augmented Reality does not reside in the simultaneous use of context and technology per se, but rather in its capacity to constitute a pedagogical mechanism that transforms contextual experience into formal mathematical representations through the process of mathematical meaning-making. It is precisely this mechanism that still requires further conceptual elucidation and empirical substantiation.

The development of research in mathematics education reflects a growing body of scholarly attention directed toward the utilization of local wisdom and Augmented Reality as strategies for enhancing the quality of mathematics learning. Although a number of studies have begun to integrate both elements, such integration has generally been positioned as a combination of learning context and technology use, with the primary focus on improving students' learning outcomes, motivation, or mathematical abilities. Consequently, understanding of the pedagogical mechanism that explains how authentic contexts derived from local wisdom are transformed through the interactive visualization of Augmented Reality into formal mathematical representations through mathematical meaning-making, thereby supporting the development of mathematical literacy, remains limited. In other words, prior research has provided evidence regarding the effectiveness of local wisdom and Augmented Reality in mathematics learning, yet has not produced a comprehensive conceptual account of the relationships among authentic context, interactive visualization, mathematical meaning-making, formal representation, and the development of mathematical literacy. It is therefore necessary to conduct research that not only examines the effectiveness of integrating local wisdom and Augmented Reality, but also explicates the pedagogical mechanism connecting these five components as a basis for the development of more meaningful mathematics learning.

Based on the gap, this study aims to elucidate the pedagogical mechanism that supports the development of mathematical literacy through the integration of local wisdom and Augmented Reality in the learning of exponents. Conceptually, this study positions local wisdom as a source of authentic context and Augmented Reality as a pedagogical mediator within a learning mechanism that transforms contextual experience into formal mathematical representations through the process of mathematical meaning-making. This perspective offers a conceptual account of the relationships among authentic context, interactive visualization, mathematical meaning-making, formal representation, and mathematical literacy—relationships that have not yet been comprehensively explained in prior research. In addition to its conceptual contribution, the findings of this study are expected to serve as a reference in designing mathematics learning that purposefully integrates local culture and digital technology in a unified manner to support the development of mathematical literacy.

2. METHOD

This study employed a Research and Development (R&D) approach to develop a local culture-based mathematics textbook integrated with Augmented Reality (AR) with the aim of improving students' mathematical literacy. The development process followed the ADDIE instructional design model, which consists of five sequential phases: Analysis, Design, Development, Implementation, and Evaluation. During the analysis phase, a mathematical literacy test consisting of four open-ended items was administered to 72 students. The test was designed to assess three core mathematical literacy competencies: (1) applying mathematics to solve problems in various real-life contexts; (2) analyzing information presented in multiple representations, including graphs, tables, charts, and diagrams; and (3) using mathematical reasoning to make predictions and support decision-making. In addition to the literacy assessment, classroom observations and in-depth interviews with mathematics teachers were conducted to identify instructional challenges, students' learning needs, and contextual issues relevant to the development of the instructional materials. In the design phase, the study focused on establishing specific learning objectives, organizing the structure of the mathematics textbook, and designing instructional content based on the local cultural practices and community activities. Relevant mathematical concepts were carefully aligned with authentic local cultural contexts to enhance students' conceptual understanding and engagement. Furthermore, the Augmented Reality (AR) learning media were designed, assessment instruments were developed, storyboards were prepared, and expert validation instruments, together with the product trial plan, were systematically constructed to ensure the quality and feasibility of the developed instructional materials.

During the development phase, the preliminary version of the mathematics textbook was developed based on the blueprint prepared in the previous design phase. This phase consisted of three main stages. First, the development of the initial draft was carried out by considering the results of the needs analysis and the characteristics of the local cultural context identified during the analysis phase. The textbook was designed based on the principles of active and independent learning, providing students with opportunities to explore mathematical concepts, construct knowledge, and strengthen conceptual understanding through authentic learning experiences. In addition, local cultural content was integrated into the topic of exponential numbers, and Augmented Reality (AR) learning media were developed to support contextual and interactive learning. Second, the product validation involved both content validation and media validation conducted by 11 mathematics teachers using expert validation instruments developed by the researchers. The content validation instrument evaluated the accuracy of exponential concepts (including positive, zero, negative, fractional exponents, and scientific notation), the clarity and measurability of the learning objectives, alignment with the junior secondary mathematics curriculum, the relevance of learning examples to the local cultural context, the accuracy and consistency of mathematical terminology, and the alignment of the instructional materials with mathematical literacy indicators. The media validation instrument assessed the clarity of illustrations, tables, and content organization, the appropriateness of learning activities, the use of communicative and student-friendly language, the inclusion of reflective and interactive learning tasks, and the suitability of the contextual learning approach to students' everyday experiences.

The final assessment instrument consisted of four open-ended tasks designed to assess students' ability to apply mathematical concepts, reason mathematically, analyze information, and solve contextual problems. The tasks required students to: (1) determine the initial amount of a grant distributed equally across schools, grade levels, and learning needs; (2) compare two payment schemes involving linear and exponential growth; (3) identify, extend, and verify a numerical pattern involving powers; and (4) simplify an expression involving the properties of exponents. These tasks represented the three mathematical literacy processes assessed in this study: formulating contextual situations mathematically, employing mathematical concepts and procedures, and interpreting mathematical results.

During the implementation phase, the developed instructional materials were implemented with 72 eighth-grade students from two junior secondary schools, namely Adisucipto Junior High School and St. Yoseph Catholic Junior High School, located in Kupang City, Indonesia. The implementation began with the administration of a pretest to assess students' initial mathematical literacy levels, followed by the learning intervention using the developed instructional materials, and concluded with a posttest to evaluate students' learning outcomes. In addition, questionnaires were administered to both students and teachers to evaluate the usability, practicality, and acceptability of the developed instructional materials.

During the evaluation phase, the quality of the local culture-based mathematics textbook integrated with Augmented Reality (AR) was comprehensively assessed based on the results of expert validation and classroom implementation. The evaluation focused on three quality aspects: validity, practicality, and effectiveness. Product validity was determined through expert evaluations of both the instructional content and the AR-based learning media. Product practicality was examined using teachers' and students' response questionnaires, as well as observations of the implementation fidelity during classroom instruction. Product effectiveness was evaluated by comparing students' mathematical literacy performance on the pretest and posttest using the normalized gain (N-gain) and effect size. The N-gain score was used to determine the magnitude of students' learning improvement, whereas the effect size was calculated to measure the strength of the instructional intervention. Based on the findings from these evaluations, the instructional materials underwent a final revision to produce a learning resource that met the criteria of being valid, practical, and effective.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Analysis Stage

Competency and Student Needs Analysis

The competency analysis identified three mathematical literacy processes relevant to exponent learning: using mathematics to solve contextual problems, analyzing information represented in different forms, and interpreting mathematical results to make predictions and decisions. Within the topic of exponents, these processes were operationalized through tasks involving the recognition of numerical patterns, the formulation and use of exponent representations, and the interpretation of solutions in real-life contexts.

An initial mathematical literacy assessment was administered to 72 eighth-grade students. As presented in Table 1, none of the three indicators reached the predetermined mastery criterion of 80%. Students achieved the highest percentage on the indicator of using mathematics to solve problems in everyday contexts (72.84%). Their performance was lower when analyzing information presented through graphs, tables, pictures, or diagrams (36.13%). The lowest percentage was recorded for interpreting analytical results to make predictions and decisions (15.83%). These results revealed particular learning needs related to translating contextual information into mathematical representations and interpreting mathematical results within their original contexts.

Table 1. Students' initial mathematical literacy performance

Indicator	Percentage
Using mathematics to solve problems in various contexts of everyday life.	72.84
Analyzing information presented in various forms (graphs, tables, sections, diagrams, etc.).	36.13
Interpreting the results of the analysis to make predictions and decisions.	15.83

Instructional Content Analysis

The analysis of the mathematics textbooks used in the participating schools showed that the exponent content covered the principal curriculum topics, including positive, zero, negative, and fractional exponents, properties of exponent operations, and scientific notation. However, the presentation of these topics was predominantly procedural. Most examples required students to apply exponent rules directly, while relatively few activities encouraged them to explain why the rules worked, recognize relationships among representations, or apply exponent concepts in unfamiliar situations.

3.1.2. Design Stage

Instructional Design Principles

The findings from the analysis stage were translated into four instructional design principles. First, exponent concepts were situated within local cultural practices familiar to students in East Nusa Tenggara. Second, contextual problems were designed to encourage students to identify relevant information and relationships rather than merely apply predetermined exponent rules. Third, the learning activities were sequenced to guide students from contextual experiences and visual patterns toward symbolic and formal mathematical representations. Fourth, AR content was incorporated to provide interactive visualizations of exponent concepts that were difficult to represent adequately through static text and images.

Corn cultivation, woven-mat patterns, traditional houses, and traditional games were selected as the principal cultural contexts. These contexts were not included merely as illustrations; each was matched with a specific exponent idea, such as repeated multiplication, numerical patterns, spatial arrangements, or exponential growth. This alignment was intended to ensure that the cultural contexts performed a mathematical and pedagogical function within the learning activities (see Table 2).

Table 2. Alignment of analysis findings and product-design specifications

Analysis finding	Design specification
Existing materials predominantly emphasized procedural exercises	Activities incorporated conceptual questions and multiple representations
Students experienced difficulty analyzing different representations	Visual, numerical, and symbolic representations were presented sequentially
Students showed the greatest difficulty interpreting results	Assessment tasks required solutions to be explained within their original contexts
Existing problems had limited connection with students' experiences	Problems were developed from familiar local cultural practices

Analysis finding	Design specification
Some exponent concepts were difficult to represent through static images	AR content was designed to provide interactive and three-dimensional visualization

Structure of the Instructional Materials

The instructional materials were organized into six components: an introduction to the cultural context, the relevant Pancasila Student Profile, learning objectives, introductory questions, core learning activities, and assessment tasks. Introductory questions were designed to activate students' prior knowledge and direct their attention to patterns or quantitative relationships within the cultural contexts. The core activities subsequently guided students to explore these relationships, represent them visually, and express them using exponent notation. The assessment tasks were aligned with the three mathematical literacy processes identified during the analysis stage. The tasks required students to formulate mathematical relationships from contextual information, employ exponent concepts and representations to obtain solutions, and interpret the resulting solutions in relation to the original contexts.

Learning Sequence and AR Integration

Each learning activity followed a sequence comprising contextual orientation, exploration, visualization, formalization, application, and reflection. Students were first introduced to a culturally familiar situation and asked to identify the patterns or quantitative relationships embedded in it. They subsequently explored the patterns using illustrations, questions, and AR-supported representations. The observed relationships were then expressed in numerical and symbolic forms before being applied to contextual problems.

For example, a corn cultivation activity was designed to represent repeated growth across successive planting cycles. Students identified the emerging numerical pattern and subsequently expressed repeated multiplication using exponent notation. In another activity, woven patterns were used to introduce repeated arrangements and relationships between quantities. AR components complemented these contexts by displaying selected patterns or objects interactively, thereby providing an additional representational bridge between the cultural situations and formal exponent expressions.

3.1.3. Development Stage

Development of the Initial Product

The initial version of the instructional materials was developed based on the specifications established during the analysis and design stages (see Figure 1). It contained exponent concepts involving positive, zero, negative, and fractional exponents, properties of exponent operations, scientific notation, and their applications in contextual problems. Local cultural contexts were incorporated into introductory situations, learning activities, illustrations, and assessment tasks, while AR components were developed to support selected visual and interactive representations.

One example involved a corn-cultivation activity in which students examined the number of plants generated across successive planting cycles. Students were guided to identify the growth pattern, express repeated multiplication, and translate it into exponent notation. Contextual questions subsequently required them to apply and interpret the resulting representation. The initial product was then evaluated through content validation, media validation, and assessment-instrument validation.

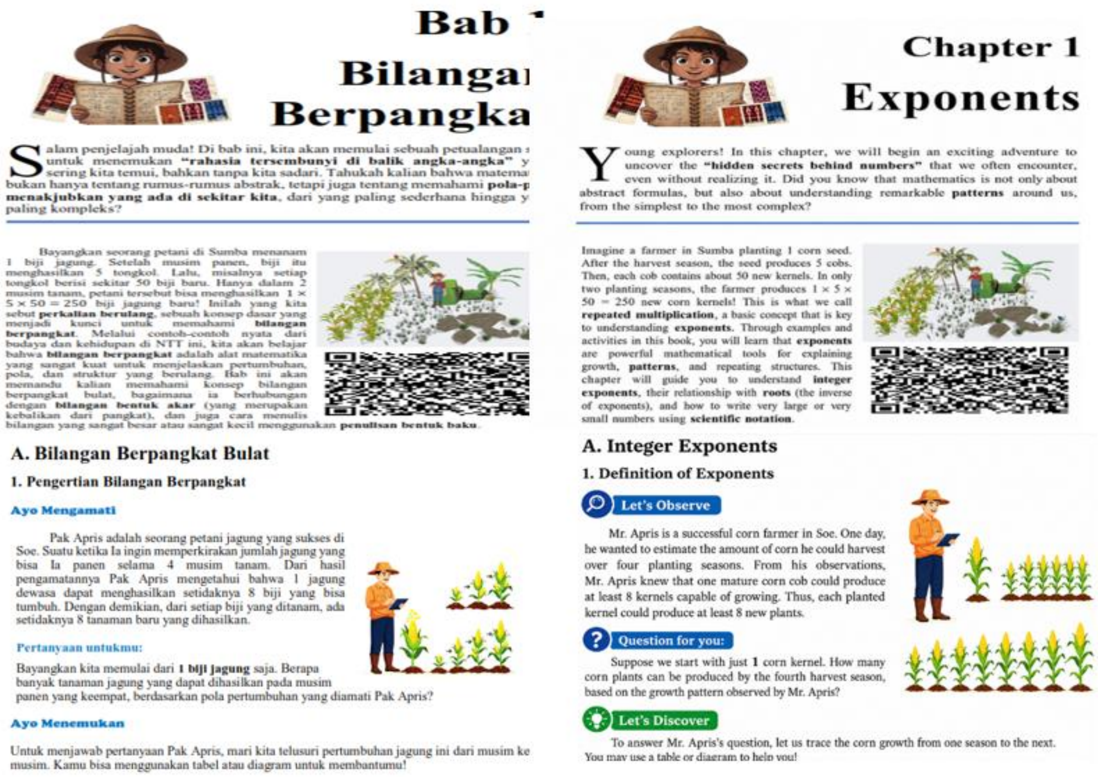

Figure 1. One of the illustrations in the teaching materials developed

Content Validation

Content validation was conducted by 11 mathematics teachers. As summarized in Table 3, the instructional materials obtained an overall mean score of 3.55 out of 4.00, categorized as very good. Scientific language obtained the highest mean score (3.91), indicating that the mathematical terminology and explanations were generally considered clear and accurate. Clarity of learning objectives (3.73) and curriculum alignment (3.64) also received high scores. Contextualization obtained the lowest score (3.18), followed by conceptual accuracy (3.27). These results indicated that several illustrations and cultural examples required refinement to establish a clearer relationship with the exponent concepts being presented. In response, selected illustrations were revised to make the represented activities more recognizable within the students' local context and to clarify their mathematical relevance. The presentation of selected exponent concepts was also reviewed to ensure consistency between contextual examples, repeated multiplication, and formal exponent notation.

Table 3. Summary of content-validation results

Validated aspect	Mean score	Interpretation
Conceptual accuracy	3.27	Very good
Clarity of learning objectives	3.73	Very good
Curriculum alignment	3.64	Very good
Contextualization	3.18	Good
Scientific language	3.91	Very good
Alignment with mathematical literacy	3.55	Very good
Overall mean	**3.55**	**Very good**

Media Validation

The media components were evaluated by the same 11 validators. The overall mean score was 3.60 out of 4.00, placing the media in the very good category. As shown in Table 4, the interactive and reflective component received the highest possible mean score (4.00). Contextual design also received a high score (3.82), indicating that the overall visual and activity design was considered relevant to students' experiences.

Readability obtained the lowest mean score (3.27), followed by visual presentation (3.36). These scores indicated the need to refine selected explanations, illustrations, and visual arrangements so that students could follow the learning sequence more easily. Accordingly, revisions focused on improving the clarity of selected illustrations, the placement of visual elements, and the correspondence between AR content and the accompanying instructions.

Table 4. Summary of media-validation results

Validated aspect	Mean score	Interpretation
Visual presentation	3.36	Very good
Integration of learning activities	3.55	Very good
Readability	3.27	Very good
Interactive and reflective components	4.00	Very good
Contextual design	3.82	Very good
Overall mean	**3.60**	**Very good**

Assessment Instrument Validation

The mathematical literacy assessment was reviewed by two mathematics teachers from the schools participating in the limited field trial. The instrument obtained an overall mean score of 3.25 out of 4.00 and was categorized as valid (see Table 5). The highest scores were obtained for using mathematics to solve contextual problems, appropriateness of data understanding and analysis, and appropriateness of critical and logical thinking, each with a mean score of 3.50.

Table 5. Summary of assessment-instrument validation

Validated indicator	Mean score
Using mathematics to solve contextual problems	3.50
Analyzing information in different representations	3.00
Interpreting results to make decisions	3.00
Appropriateness of data understanding and analysis	3.50
Application of mathematics in real-world contexts	3.00
Appropriateness of critical and logical thinking	3.50
Overall mean	**3.25**

The validators' assessments indicated that the instrument was suitable for use with eighth-grade students. Nevertheless, items related to analyzing representations and interpreting results required particular attention during final review because these indicators obtained lower scores and corresponded to the areas in which students had demonstrated the greatest initial difficulty. The wording and contextual information in these items were therefore reviewed to reduce ambiguity while retaining the intended cognitive demand.

Product Revision

The quantitative validation results were used to prioritize revisions to the initial product. The revisions focused on three aspects: strengthening the mathematical relationship between cultural contexts and exponent concepts, improving the readability and organization of selected visual materials, and clarifying the wording of assessment tasks. Following these revisions, the instructional materials and assessment instrument were prepared for the limited implementation stage.

3.1.4. Implementation Stage

Limited Field Implementation

The revised instructional materials were implemented with 72 eighth-grade students from Adisucipto Junior High School and St. Yoseph Catholic Junior High School in Kupang, Indonesia. During the implementation, students engaged with exponent-learning activities that combined local cultural contexts, printed instructional materials, and AR content accessed through mobile devices. Teachers facilitated the activities by guiding discussions, helping students connect cultural situations with mathematical representations, and assisting them in accessing the AR components.

The implementation documentation illustrates three central components of the learning process. Figure 2(a) shows students accessing AR content using mobile devices with teacher assistance. Figure 2(b) presents woven palm-leaf patterns as one of the local cultural contexts used in the instructional materials. Figure 2(c) shows an AR marker through which students accessed three-dimensional or animated learning content. Together, these figures demonstrate how the printed materials, cultural contexts, AR representations, and teacher facilitation were combined during classroom implementation.

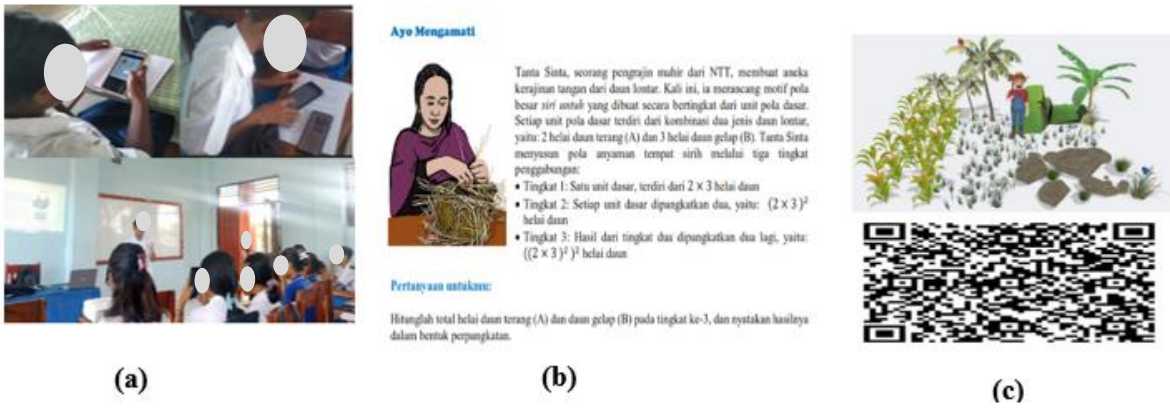

Figure 2. Classroom implementation of the instructional materials: (a) students accessing AR content with teacher guidance; (b) a local woven-mat context; and (c) an AR marker embedded in the instructional materials

Student Responses

Students' responses were analyzed to examine the practicality and acceptability of the instructional materials (see Table 6). Twenty-five of the 72 students who participated in the implementation completed the response questionnaire. The questionnaire consisted of 10 items rated on a four-point scale. The practicality percentage was calculated by dividing the total score obtained by the maximum possible score and multiplying the result by 100.

Table 6. Student responses to the instructional materials

Assessed aspect	Maximum score	Score obtained	Percentage
Content understanding	300	245	81.67%
Readability and visual presentation	200	162	81.00%
Learning engagement	300	239	79.67%
Benefits and relevance	200	165	82.50%
Overall	**1,000**	**811**	**81.10%**

The questionnaire obtained a total score of 811 out of a maximum possible score of 1,000, resulting in an overall practicality percentage of 81.10%. Benefits and relevance obtained the highest percentage (82.50%), followed by content understanding (81.67%), readability and visual presentation (81.00%), and learning engagement (79.67%). Based on the predetermined criteria, the instructional materials were categorized as very practical.

Students' written responses also provided information about their experiences. One student stated, "The pictures in this material are interesting and help me understand more easily," while another reported, "These video animations make me enjoy mathematics lessons more." These responses indicated that the students perceived the combination of visual representations and familiar contexts as engaging and helpful.

However, implementation difficulties were also identified. Some students experienced problems when logging into the application and scanning the AR markers. Students also reported difficulties with selected contextual problems, particularly when the problems differed from the examples provided in the materials. These responses showed that high overall practicality did not eliminate the need for technical assistance, additional examples, and instructional scaffolding.

Teacher Responses

The participating teacher's response was evaluated across five aspects: learning preparation, delivery of materials, student interaction, practice and application, and learning evaluation. The obtained score was divided by the maximum possible score and multiplied by 100. As presented in Table 7, the teacher questionnaire produced a score of 48 out of 50, equivalent to 96%, and was categorized as *very practical*.

Table 7. Teacher responses to the instructional materials

Assessed aspect	Maximum score	Score obtained	Percentage (%)
Learning preparation	10	10	100
Delivery of materials	10	10	100
Student interaction	10	10	100
Practice and application	10	9	90
Learning evaluation	10	9	90
Overall	**50**	**48**	**96**

The highest scores were recorded for learning preparation, material delivery, and student interaction. Slightly lower scores were recorded for practice and application and for learning evaluation. The teacher noted that the materials helped connect abstract exponent concepts with students' everyday experiences and introduced local cultural values within mathematics learning. The teacher also reported that the AR displays supported students' interest during the learning activities.

Overall, the student and teacher responses indicated that the instructional materials were practical for use in the limited classroom implementation. Nevertheless, the technical difficulties associated with accessing AR content and the lower teacher scores for application and evaluation identified aspects requiring further refinement.

3.1.5. Evaluation Stage

The magnitude of the change in students' mathematical literacy scores was examined using Cohen's d_z, which is appropriate for paired pretest–posttest data (see Table 8). The mean score increased from 58.72 (SD = 12.64) on the pretest to 82.57 (SD = 11.80) on the posttest. The mean difference was 23.85 points, with a 95% confidence interval ranging from 21.54 to 26.15. A paired-samples t-test indicated that the increase was statistically significant, $t(71) = 20.63$, $p < 0.001$. The resulting effect size was very large, Cohen's $d_z = 2.43$, 95% CI [1.97, 2.89]. The bias-corrected estimate was similarly large, Hedges' $g_z = 2.41$. These results indicate a substantial within-group improvement in students' mathematical literacy scores following the implementation of the instructional materials.

Table 8. Pretest - posttest statistical comparison

Measurement	Mean	SD	Mean difference	95% CI	(t)	(p)	Cohen's (d_z)
Pretest	58.72	12.64	23.85	[21.54, 26.15]	20.63	< 0.001	2.43
Posttest	82.57	11.80					

The mean individual N-gain was 0.60, which was categorized as moderate. Of the 72 students, 5 students (6.9%) obtained a low N-gain, 41 students (56.9%) obtained a moderate N-gain, and 26 students (36.1%) obtained a high N-gain. Thus, most students demonstrated moderate or high improvement, although the magnitude of improvement varied across participants (see Table 9).

Table 9. Distribution of students' N-Gain scores

N-gain category	*n*	Percentage
Low	5	6.9%
Moderate	41	56.9%
High	26	36.1%
Total	**72**	**100%**

These findings provide evidence of a statistically significant and educationally substantial improvement in students' scores following the implementation of the instructional materials. Nevertheless, because the evaluation employed a one-group pretest–posttest design without a comparison group, the observed improvement cannot be attributed exclusively to AR or local wisdom. The change reflects the implementation of the instructional approach as a whole, including the instructional materials, cultural contexts, AR representations, learning activities, and teacher facilitation.

3.2. Discussion

The findings demonstrate that the instructional materials integrating local wisdom and Augmented Reality were valid, practical, and associated with substantial improvement in students' mathematical literacy scores. Students' mean score increased from 58.72 to 82.57, with a moderate mean N-gain of 0.60. A paired-samples t-test revealed a statistically significant increase, $t(71) = 20.63$, $p < 0.001$, with a very large within-group effect size, Cohen's $d_z = 2.43$. These two measures provide complementary information: the N-gain represents improvement relative to the maximum score students could attain, whereas Cohen's d_z represents the magnitude of the paired change relative to the variability of individual score differences. Nevertheless, these findings should be interpreted as evidence of improvement following the implementation of the instructional approach as a whole, rather than as evidence of the isolated effects of either AR or local wisdom.

The findings can be interpreted through the three mathematical literacy processes of formulating, employing, and interpreting. At the formulating stage, culturally familiar situations provided an accessible starting point for identifying quantities, patterns, and relationships relevant to exponent concepts. Corn cultivation, woven-mat patterns, traditional houses, and traditional games enabled students to begin mathematical activity from situations connected with their social and cultural experiences. This finding is consistent with previous research (Hendriana et al., 2025; Labuem et al., 2026; Nurcahyo et al., 2024; Nursyahidah et al., 2025; Prahmana et al., 2026; Rodríguez-Nieto et al., 2025; Umbara et al., 2025; Umbara et al., 2023; Umbara et al., 2026), which demonstrated that ethnomathematical practices intersect with mathematical literacy through mathematical content, contexts, and processes embedded in everyday cultural activities. Thus, local wisdom functioned not merely as an illustrative background but as an epistemic context from which mathematical relationships could be identified and expressed.

However, familiar contexts did not automatically enable students to formulate mathematical models independently. Students continued to experience difficulties when contextual problems differed from the examples provided in the instructional materials. This pattern suggests that contextual familiarity helped students enter the problem situation, but additional scaffolding was required to identify relevant variables, recognize underlying relationships, and translate those relationships into exponent expressions. Consequently, local wisdom should not be treated as a direct substitute for mathematical modelling instruction. Teachers still need to use guiding questions, comparisons among representations, and progressively varied problems to help students move from contextual understanding to mathematical formulation.

The most visible contribution of the developed materials appeared in the employing process. Students were generally better able to use exponent concepts when problems involved patterns or representations resembling those explored during instruction. AR provided interactive visual representations that connected contextual objects, repeated multiplication, and symbolic exponent notation. This interpretation is consistent with Bujak et al. (2013), who explained that AR can connect physical manipulation, visual representation, and mathematical symbols. It also aligns with Nindiasari et al. (2024), whose study in Infinity Journal showed that AR integrated with a pedagogical approach supported students' mathematical problem-solving performance. Together, these findings suggest that the pedagogical value of AR does not arise solely from presenting three-dimensional or animated objects, but from coordinating those representations with mathematical questions, symbolic expressions, and teacher-guided activities.

From the perspective of multimedia learning, the combination of verbal explanations, cultural illustrations, AR visualizations, and symbolic expressions may have supported students in organizing complementary representations of exponent concepts (Mayer, 2020). Nevertheless, this interpretation should remain theoretical because the present study did not directly measure cognitive load, attention allocation, or multimedia-processing mechanisms. The findings therefore do not demonstrate that AR reduced cognitive load. Instead, they show that students and the participating teacher perceived the visual and interactive representations as useful and engaging, while the pretest–posttest results indicated substantial improvement following the complete instructional intervention.

The interpreting process remained more challenging. Although students could apply exponent procedures and representations, some had difficulty explaining what their results meant in the original context, particularly when they encountered unfamiliar contextual problems. This distinction is important because mathematical literacy does not end when a numerical answer is obtained; students must also evaluate whether the result is reasonable and communicate its meaning within the problem situation. The findings indicate that visualization and cultural familiarity primarily facilitated access to and application of mathematical ideas, whereas the transition from mathematical results back to contextual meaning required more explicit reflective activities. Prompts such as “What does this value represent?”, “Is the result reasonable in this cultural situation?”, and “How would the result change if the contextual conditions changed?” could strengthen this process.

The principal theoretical contribution of this study therefore lies in the proposed pedagogical mediation mechanism. The integration did not simply place cultural content and AR technology within the same instructional material. Instead, the intended learning sequence operated through culturally meaningful experience, exploration of quantitative patterns, AR-supported visualization, formal exponent representation, contextual application, and interpretation. In this mechanism, local wisdom provided the source of meaning, AR supported representational transition, and teacher scaffolding coordinated movement between contextual and formal mathematical knowledge. The mechanism can be summarized as follows: authentic cultural context → exploration of mathematical relationships → AR-supported visualization → formal mathematical representation → contextual application and interpretation.

Nevertheless, the study design cannot determine the individual contribution of each component. Students’ improvement may also have been influenced by prior knowledge, teacher facilitation, novelty and motivation associated with the AR activities, repeated exposure to exponent problems, and differences in digital literacy. The one-group pretest–posttest design did not include a comparison group receiving local-wisdom materials without AR or AR materials without local wisdom. Consequently, the proposed mechanism is theoretically and empirically plausible, but its component-specific effects require further investigation.

The findings also have practical implications. Teachers need more than technical competence in operating AR applications; they must be able to select culturally authentic contexts, formulate questions that reveal their mathematical structure, and provide scaffolding between contextual, visual, and symbolic representations. Curriculum developers should ensure that local wisdom is integrated through mathematically meaningful activities rather than used as decoration. Schools also need to consider device availability, internet access, application stability, and technical support because some students experienced difficulty logging into the application and scanning AR markers. Without adequate infrastructure and teacher preparation, technology-supported instruction may increase rather than reduce inequalities in learning opportunities.

Several limitations should be acknowledged. The intervention involved 72 students from two schools, while the student-response questionnaire was completed by only 25 participants. Practicality findings should therefore be interpreted as the perceptions of this respondent subgroup. The study also involved one participating teacher’s practicality assessment, focused on one mathematical topic, and examined learning over a limited implementation period. Furthermore, the absence of a comparison group limits causal inference and prevents the separate contributions of AR and local wisdom from being identified. Future studies should employ comparative or factorial designs, analyze students' performance separately across formulating, employing, and interpreting processes, and investigate whether the observed improvement is sustained across different mathematical topics and longer periods of instruction.

4. CONCLUSION

This study developed mathematics instructional materials that integrate local wisdom and Augmented Reality to support mathematical literacy in exponent learning. The materials met the established validity criteria for content and media and were considered practical by both students and the participating teacher. Following their implementation, students' mean mathematical literacy score increased from 58.72 to 82.57, with a moderate N-gain of 0.60 and a very large within-group effect size (Cohen's $d_z = 2.43$). These findings indicate substantial improvement after the implementation of the instructional approach as a whole.

The principal contribution of this study lies in the pedagogical mechanism through which culturally familiar experiences are explored, visualized through AR, and transformed into formal mathematical representations. The materials appeared particularly useful in supporting students' engagement and their ability to employ exponent concepts. However, some students continued to experience difficulty formulating mathematical models from unfamiliar contexts and interpreting mathematical results within their original situations. Therefore, integrating context and technology still requires carefully designed teacher scaffolding.

The study used a one-group pretest–posttest design, involved two schools, and focused on one mathematical topic. The observed improvement cannot be attributed exclusively to either AR or local wisdom. Future research should employ comparison groups, examine the separate and combined contributions of both components, analyze the processes of formulating, employing, and interpreting independently, and investigate the sustainability of learning outcomes across topics and implementation periods.

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Declarations

Author Contribution : SIL: Conceptualization, Supervision, Writing - original draft, and Writing - review & editing; ML: Data curation, Formal analysis, Methodology, Resources, and Writing - original draft; YOJ: Data Curation, Formal analysis, and Methodology; KDD: Formal analysis, and Writing - review & editing; WBND: Investigation, Visualization, Writing - original draft, and Writing - review & editing; DAK: Validation.

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