International Research Journal of Multidisciplinary Scope (IRJMS),2026;7(2):916-932

Original Article | ISSN (O): 2582-631X DOI: 10.47857/irjms.2026.v07i02.010196

Local Culture-based Learning Design with Technology Integration to Improve Students' Numeracy Skills on Number Content

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Abstract

Numeracy is an essential foundational skill for students to comprehend and apply mathematical concepts in daily life, serving as the basis for cultivating critical and logical thinking abilities necessary to navigate challenges in the digital age. But the 2022 Program for International Student Assessment (PISA) study shows that Indonesian students' math skills are still below the world average. The National Assessment results from 2024 show that junior high school students in the Malaka district still have "very poor" literacy and numeracy skills. The goal of this research is to create a way for students in Malaka to learn about local culture and use technology to help them get better at math. An HLT was created using a design research method. The research tools are numeracy tests, observation sheets, and rules for conducting interviews. The pilot experiment uncovered significant challenges, including misunderstandings regarding negative numbers and obstacles in translating context to symbols. The teaching experiment demonstrated substantial enhancements in numeracy skills and heightened learning motivation. These results show that combining local culture and technology in math lessons works to help students understand concepts better and improve their math skills. The outcome of this research is local instructional theories (LIT) tailored for the acquisition of integers, aimed at enhancing students' numeracy skills.

Keywords: Design Research, Local Culture, Numbers, Numeracy, Technology.

Introduction

Students need to have numeracy skills to understand and use math ideas in their daily lives. Numeracy is important for more than just schoolwork; it's also important for making decisions, solving problems, and being an active member of society (1). In education, numerical literacy lays the foundation for developing critical and logical thinking, which is absolutely necessary to face the challenges of the digital era (2–4). Typically, students with strong numeracy skills demonstrate superior academic performance and the ability to adapt to changes in technology and society (5, 6). Thus, greater numerical literacy good practices not only benefit society but also help produce a more competent and competitive society.

However, according to the results of the 2022 Programme for International Student Assessment (PISA), Indonesian students' numeracy skills are still below the world average. with a score of 379, well below the Organization for Economic Co-operation and Development (OECD) average of 489. This value places Indonesia in 72nd place out of 78 participating countries. In addition, the 2019 PISA results show that only 1% of Indonesian students reached the highest level of competency (level 5 and 6) in numeracy skills, while 74% of students are below the basic competency level (level 2). The figure indicates a significant gap in the mastery of numeracy, especially in areas categorized as disadvantaged, frontier, and outermost.

Malaka district is one of the areas with quite complex educational challenges. Factors such as limited access to technology, lack of variety in learning media, and low involvement of local culture in the learning process contribute to students' low numeracy (7). The results of the National Assessment in 2024 showed that students in Malaka who achieved the minimum competenc-

(Received 20th December 2025; Accepted 17th March 2026; Published 14th April 2026)

ies in literacy and numeracy did not reach 40% (8). This condition was experienced at one of the junior high schools in Malaka District. Based on the results of interviews with one of the mathematics teachers, it was found that the problem that has been a scourge for students so far is the low numeracy skills, especially in number content. Furthermore, the interview with the teacher explained that there are several factors that cause this problem, including the selection of learning methods that are not innovative, students not being trained to work on numeracy problems in class, limited utilization of technology in mathematics learning, and the absence of learning media that integrate local culture. This series of factors causes students not to have good numeracy skills.

Local culture has great potential to be utilized as a contextual and meaningful learning medium for students, especially the indigenous culture of the Malaka district. There are several local cultures of the Malaka district community that can be integrated into learning. Particularly in a place with many different cultures like Indonesia, learning that centres on local culture is quite important in raising the meaning and relevance of education. This approach helps students connect their daily experiences with the instructional material, thereby increasing their interest, motivation, and comprehension (9). Furthermore, teaching that emphasizes local culture promotes the preservation of cultural legacies and helps strengthen pupils' identities in relation to their cultural roots (10). This method therefore not only improves academic performance but also reinforces indigenous wisdom and so fosters cultural pride.

Conversely, particularly in the digital age when changes in information and communication call for adaptation, technology-based learning is vital in raising the standard of education. Interactive applications, e-learning websites, and augmented reality (AR) content let students explore learning resources in a way more customized to their individual learning styles (11–13). Using technology in the learning process can boost student motivation, engagement, and results since it can provide abstract ideas in a visual and interactive way. Moreover, technology promotes a more customized and flexible learning style whereby teachers can track student development in real time and offer quicker comments (14). Therefore, technologically based learning not only enhances the efficacy of the learning process but also equips pupils with the skills required in the twenty-first century. This is especially important as critical thinking and digital literacy skills continue to grow.

Numerous earlier studies have investigated how mathematics education can incorporate regional culture and technology. For example, past research has shown that integrating Boti cultural elements into mathematics instruction can create a more relevant learning experience for students, enhancing their interest and confidence in studying mathematics. This approach focuses on academic success and helps students understand, value, and appreciate their cultural heritage (15). The research conducted in the past indicates that incorporating GeoGebra technology into Mathematics education, particularly for understanding nets of flat-sided geometric forms, can enhance students' ability to visualize abstract shapes (16). However, there are still few studies that integrate the two approaches simultaneously, especially in the context of numeracy in rural areas.

Researchers are interested in doing research under the heading "Local Culture-Based Learning Design with Technology Integration to Improve Students' Numeracy Skills on Number Content." This research aims to design local culture-based learning with technology integration that can improve junior high school students' numeracy skills. The numeracy skills mentioned are not just the ability to do math; they are a basic skill that includes a deep understanding of math concepts, the ability to reason well, and the ability to use math in everyday situations. Furthermore, this contextual approach expects students to build a strong foundation through a solid mastery of number content.

Methodology

This work utilizes educational design research, elucidating the nature of the research undertaken. Educational design research is a careful study that looks at how to create, use, and assess educational programs, tools, and teaching methods to solve complex problems in education. This method also aims to enhance our comprehension of the attributes of these interventions and the design methodology (17). Design research aims to generate Local Instructional Theory (LIT), a framework for the learning process that emphasizes collaboration between researchers and educators to improve educational quality. LIT delineates a learning trajectory in a particular domain, underpinned by a sequence of activities (18).

The main part of design research is classroom activities that focus on making learning trajectories and the LITs that support them. Generally, the learning outcomes for LIT represent the final results of creating, implementing, and analysing the Hypothetical Learning Trajectory (HLT). Particularly, this study seeks to create a contextualized LIT based on the local culture of Malaka district and technology-driven to enhance the Grade VII students' numeracy skills in number content. This research followed the stages of designing HLT to become LIT. This research was conducted in three main stages: preliminary design, experimental design, and retrospective analysis outlined in Figure 1.

This research was conducted in one of the public junior high schools in the Malaka district, East Nusa Tenggara, Indonesia. This research was conducted in July 2025. The selection of the research location and time was based on the results of the needs analysis, which found the problem of low numeracy skills, especially in number content.

The participants in this study were 7th grade students who are currently in the age range of 14–15 years old. In the experimental pilot class, there were 5 students, consisting of 3 girls and 2 boys, while in the experimental teaching class, there were 30 students, consisting of 16 girls and 14 boys. Students in the pilot and teaching classes are different students. Pilot experiments were carried out in class 7b while teaching experiments in class 7a. The subject distinction between pilot experiments and teaching experiments in design research is a critical methodological principle to ensure the validity and reliability of learning designs before they are applied on a larger scale. Pilot experiments usually involve a limited number of subjects aiming to identify design issues, instrument feasibility, and initial response to the intervention. The pilot experiment in this study concentrated on enhancing the HLT, teaching aids, and instruments via comprehensive feedback. The teaching experiment utilized a larger sample size to evaluate the design's efficacy in real-world conditions and to extrapolate the results (19).

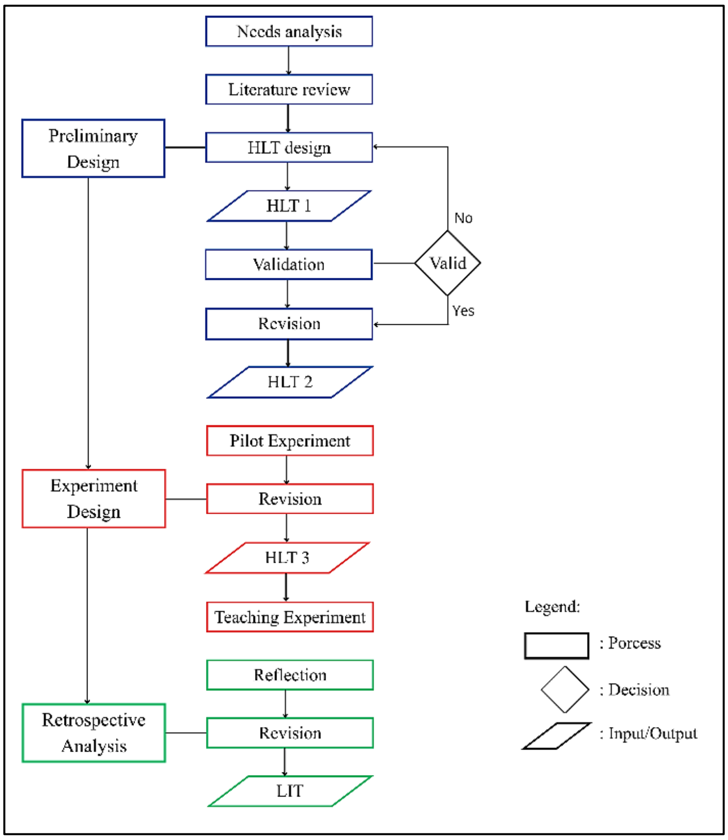

Figure 1: Research Procedure

The research utilized observation sheets, interview guidelines, and numeracy tests, employing a data collection process that combined observations, tests, and interviews. Each instrument underwent validity testing prior to application. The results from the observations serve as the basis for reviewing and modifying the learning design. Observations ensure that the HLT continually improves its effectiveness. Observations can corroborate data collected through tests, interviews, or exams. Interviews provide students and instructors with an opportunity to offer feedback and suggestions for enhancing the learning design. This feedback is very helpful for making changes to the learning design. Interviews also help confirm results from other methods, which makes the research as a whole more valid. This study utilized both a pre-test and a post-test. The results of the pre-test and post-test numeracy tests will be analysed quantitatively to measure the effectiveness of the learning design. This analysis encompasses the computation of the average score, the assessment of competency enhancement via the N-Gain test, and the determination of the percentage of student learning completion. This quantitative data provides an objective picture of the extent to which the learning design contributes to improving students' numeracy skills. In addition to being an indicator of effectiveness, the results of this analysis are also used as a basis for revising and refining the HLT so that the design improvement process is based on qualitative observations and supported by empirical evidence of student learning outcomes.

Results

This research was conducted in three main stages: preliminary design, experiment design, and retrospective analysis. The first stage, referred to as preliminary design, encompasses several sub-stages, including needs analysis, literature review and HLT design.

The needs analysis phase employed a multi-method approach, integrating field observation, document analysis, and surveys to identify the gap between actual and ideal numeracy learning conditions. This initial stage involved observations at the research site to evaluate the learning process. The findings reveal that most students struggle with the concept of integers, while teachers have not consistently integrated local culture into their instruction. This observation is consistent with research by Jabal, which indicates that Indonesian students frequently hold misconceptions about negative numbers due to an abstract understanding that lacks contextual grounding (20).

The second phase was in-depth interviews with Malaka traditional leaders, who discovered that the Batar Manaik tradition (corn tribute system to the king) might potentially be used. Mathematical backgrounds for number operations can be provided by tribute systems to the king, local dances, and weaving patterns, as underlined by Putra, showing that ethnomathematics connects informal and formal knowledge (21).

The third phase involved a technology evaluation conducted through a questionnaire distributed to mathematics instructors in the research locations. The results indicated that most teachers relied on basic interactive tools, such as PowerPoint and iSpring Suite, along with other technologies. However, these tools proved to be limited in their effectiveness for creating successful lessons. Previous research supports this conclusion, suggesting that the effectiveness of technology integration is influenced by teachers' capabilities and the local context.

The fourth stage involves interviewing teachers about students' numeracy skills. The findings indicate that students' numeracy skills remain very low because teachers rarely focus on developing these skills. Classroom exercises often rely on conventional problems that utilize formal mathematical symbols, lacking any social or cultural context. The synthesis of these stages leads to several learning design recommendations that include:

(a) Integrating local cultural contexts for recognizing integers,
(b) Employing concrete media in learning
(c) Utilizing interactive PPT-based technology and
(d) Providing intensive numeracy training.

The next phase involves the literature review stage, which was carried out in four key steps (22). The text is generally clear and maintains a consistent tone, but slight adjustments can enhance clarity and flow. Here's a revised version: First, core topics were identified and categorized into three key areas: local culture-based learning, technology integration in mathematics education, and numeracy within number content. A literature search was conducted using Scopus, ERIC, and SINTA-indexed databases, utilizing keywords such as "ethnomathematics," "technology-enhanced mathematics learning," and "numeracy." This search yielded relevant articles published within the last five years. The second stage involved a critical evaluation of the literature findings. Previous studies indicated that 72.22% of students experienced enhanced mathematical communication skills through the ethnomathematics approach, While a meta-analysis proved that computer technology-assisted learning and behavioral interventions are more effective in improving student achievement (23). However, a research gap was identified due to the simultaneous lack of integration between cultural and technological approaches.

In the third step, the results are combined to develop a theoretical framework. Through cultural and physical experiences, culture-based learning improves conceptual knowledge, according to the notion of embodied cognition (24). Furthermore, cognitive load theory supports the integration of technology to visualize abstract numerical concepts (25). The synthesis shows that multimodal representation can result in real misconceptions when local culture and technology are combined (26). Creating a conceptual map that connects the research variables is the last step. Local cultural context as the basis for learning, technology as a scaffold, and numeracy as the end result is all included in the final framework.

HLT Design

This study employed a design research methodology to integrate the four principal components of the HLT design stages: learning objectives, learning activities, cognitive speculation, and anticipation. A requirements study revealed that students must comprehend numbers within a cultural framework; thus, the initial step involved establishing learning objectives. The learning goals were set so that students could reach PISA level 3 numeracy skills. This means they could use whole number operations and reasoning to solve problems in context. The second stage's main theme was the Batar Manaik tradition, which involves giving maize as a gift to the tribal king. The activities were based on the idea of embodied cognition, which means that students use integer beads to show how a profit-sharing deal works in a physical way before moving on to more abstract ways of doing it. The third stage predicts the hypothetical learning process by anticipating that students will have initial misconceptions due to everyday experiences with positive numbers. The result of this stage is HLT 1 which is described in Table 1.

The learning goals of HLT 1 are as follows:

(a) Students can explain the definition of integers,
(b) Students can describe the properties of integers,
(c) Students can sort integers and
(d) Students can perform addition and subtraction operations on integers.

Table 1: HLT 1

Learning Activities	Activities Goals	Thinking Conjectures	Anticipations
Informal Students observe the problem of debt in the Batar Manaik (Offerings to the King) culture of the Malaka people.	Students comprehend integers through the local cultural context of the Malaka district.	Students perceive negative numbers as representing "corn debt" owed to the king, positive numbers as indicating "corn availability," and zero as the point when the corn is "used up".	However, students may struggle to understand negative numbers in this context. To address this, the teacher prepares by simulating the process of offering corn in the classroom.
Model of Concrete Students are provided with simulations of concrete representations of integers, a ruler, and integer beads. They then conduct a demonstration using a number ruler and integer beads.	The objective is to help students who are in the concrete operational stage grasp the principles and processes of adding and subtracting integers. Additionally, the aim is to support students with kinaesthetic learning styles	Students learn the order of integers through demonstrations with number ruler props. They can also perform addition and subtraction operations with integer bead props.	Students may not be able to understand the order and operations of the addition and subtraction of integers, so teachers need to guide discussions in small groups more intensely with the help of other co-teachers in Team Teaching.
Model for Semi-Concrete Students are given simulations of integer addition and subtraction operations using technology-based learning media (PPT/Canva).	Facilitate students with audio-visual learning styles to understand the operations of adding and subtracting integers more deeply.	Students can understand integers' addition and subtraction operations more deeply through teacher explanation using technology-based learning media (PPT/Canva).	Students may need more time to understand integer addition and subtraction operations, so teachers collaborate to guide learners individually and in groups.
Formal Mathematics Mathematical symbols are presented to the students, including operation symbols for adding and subtracting integers as well as integer symbols. Additionally, they are given practice problems that concentrate on number ordering and integer addition and subtraction.	Introducing students to formal math symbols in integers' addition and subtraction operations.	Students understand mathematical symbols and are able to solve integer addition and subtraction operations using mathematical symbols correctly.	Students may not be ready with formal mathematical symbols, so students are allowed to reuse concrete props to solve the given problem.

Numeracy Students are presented with numeracy problems that incorporate the local cultural context of the Malaka district. These problems involve number content designed toengage students at various levels of thinking processes for solving them.	Train students to solve numeracy problems in various levels of thinking processes.	Students are able to solve numeracy problems with the local cultural context of the Malaka district and number content in various levels of the thinking process.	Students may need more time to solve numeracy problems, so teachers collaborate to guide learners individually and in groups.

Validation

The HLT 1 design was validated by two mathematics education experts and one local culture expert, who used a validation instrument. Based on Table 2, the findings revealed a suitability level, assessed by the content validity index, of 3.87 out of a possible 4 for the cultural contextualization component and 3.79 for technology integration.

Table 2: HLT Design Validation Results by Experts

Aspect Assessed	Validation Result (Mean Score)	Maximum Score	Description
Cultural Contextualization	3.87	4	Highly Valid / Highly Suitable
Technology Integration	3.79	4	Highly Valid / Highly Suitable

The experts recommended several improvements, among others:

(a) Change the terms in Malaka culture accordingly,

(b) Adding group discussion activities to improve student collaboration and

© adding feedback features in the interactive PPT to overcome difficulties in negative number operations.

HLT 1 was then revised according to the validators' comments and suggestions to change into HLT number 2.

Development Of Numeracy Test

The numeracy evaluation tool was created using the PISA framework's process (formulate, employ, and interpret) and context (personal, occupational, and societal) dimensions. There are 10 questions on the instrument, which are split into three levels: level 1 (understanding), level 2 (application) and level 3 (reasoning). Two methods were used to test the validity of the numeracy evaluation tool: content validity and construct validity. Three experts (two in math education and one in evaluation) used the content validity index (CVI) to test content validity.

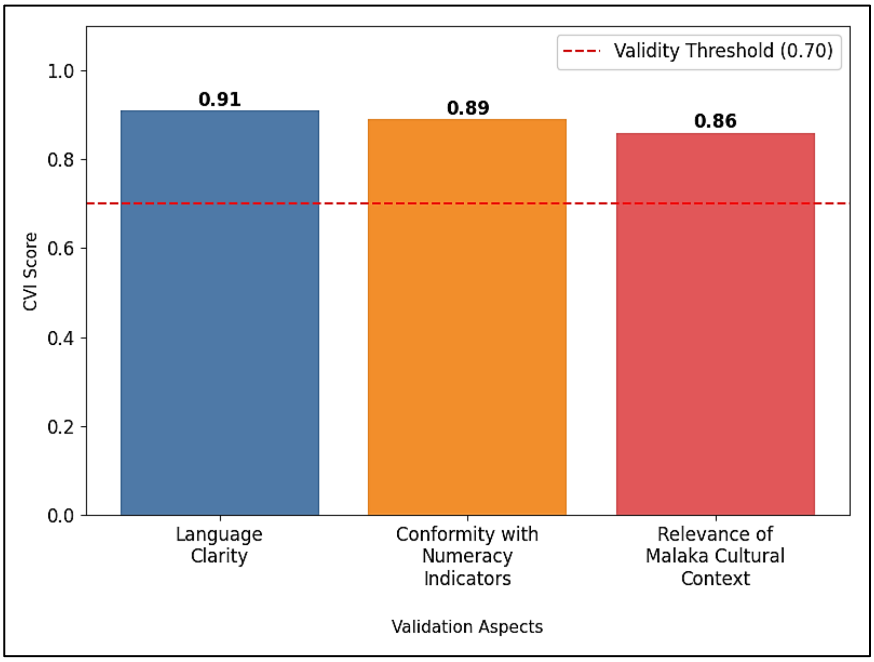

Figure 2. Content Validity Scores

According to Figure 2, the results showed a CVI score of 0.89 for the aspect of conformity with numeracy indicators, 0.86 for the relevance of the Malaka cultural context, and 0.91 for language clarity. A CVI score of >0.70 is considered to meet the validity criteria (27).

According to Table 3, confirmatory factor analysis (CFA) was used to test construct validity on 30 respondents. The CFA results showed that each item's factor loading value was between 0.68 and 0.85, and the goodness-of-fit values met the criteria. This means that the instrument measures the numeracy construct correctly (28).

Table 3: Construct Validity Test Results

Test Aspect	Indicator / Test Result	Ideal Criteria	Description
Number of Respondents	30 respondents	-	Sample size for instrument testing
Factor Loading	0.68 – 0.85	> 0.50	Valid, all items contribute well to the construct.
Chi-Square / df (χ^2/df)	1.85	< 2.00	Fit (Goodness-of-fit is acceptable).
Comparative Fit Index (CFI)	0.93	> 0.90	Fit (Goodness-of-fit is acceptable).
Root Mean Square Error of Approximation (RMSEA)	0.06	< 0.08	Fit (Goodness-of-fit is acceptable).

Based on Table 4, a reliability test was conducted with the internal consistency method using Cronbach's alpha. Based on tests on 30 junior high school students, an alpha value of 0.84 was obtained for all instruments, with alpha values for each numeracy dimension as follows: formulate (0.79), employ (0.81), and interpret (0.83). Alpha values > 0.70 indicate high internal consistency (29).

A test-retest study with 25 students over a 14-day period also showed that the tool was stable, with a correlation coefficient of 0.87 ($p < 0.01$). We also did an item analysis to see how good the questions were. The item-total correlation values were between 0.35 and 0.68, which is higher than 0.30. The questions also had a difficulty index that went from 0.40 to 0.75, which put them in the middle of the pack. These results show that the instrument has a good amount of complexity and differentiation.

Table 4: Reliability Test Results (Cronbach's Alpha)

Aspect	Cronbach's Alpha (α)	Ideal Criteria	Description
Overall Instrument	0.84	> 0.70	Highly Reliable / Good Internal Consistency
Dimension Formulate	0.79	> 0.70	Reliable / Acceptable Internal Consistency
Dimension Employ	0.81	> 0.70	Highly Reliable / Good Internal Consistency
Dimension Interpret	0.83	> 0.70	Highly Reliable / Good Internal Consistency

These tests show that the Numeracy tool works well. This is because it was very strict with the numbers. This is a good way to test the skills of students in our area. This is because our kids need to learn how to use math in real life, not just how to count or use numbers.

Experiment Design

Design experiment (also called design-based research) is a research approach that focuses on iteratively developing and testing learning innovations in real contexts. Design trials are conducted in three iterative stages, consisting of a pilot experiment, revision, and teaching experiment.

The first trial is a small class trial or pilot experiment. This phase is crucial for identifying practical problems when HLT is implemented in the classroom. Before the pilot experiment, a pre-test was given to see how well the students understood the basic material, especially integers and how to work with them. There were 5 students in the pilot class, 2 boys and 3 girls. The questions were about numbers, specifically integers, which PISA divides into three levels: understanding, application, and reasoning. There were six questions, and they were all about descriptive statistics. Students answered the questions by filling out the question sheet directly.

To implement HLT 2, five interconnected HLT stages were used, along with Malaka's local culture and concrete and technology-based learning media, as well as student activity sheets to help students learn and improve their math skills. In the first phase, the informal phase, students learn about integers by using the Batar Manaik tradition, which is a Malaka system for sharing agricultural production. In the culture of Batar Manaik, each group of people brings corn as a gift. The corn is placed in one place to be checked by an assigned person to ensure that all the people have collected it. Once all the corn has been collected, the officer again signals the tribal groups to enjoy attractions such as the Likurai, Tebe Bot, Lalok Dato, and Hananu*.* Here are dances that herald the introduction of the tributes and enliven the culminating event. Next, the tributes are placed on mats spread out in the front yard of the Malaka traditional house, where several elders are waiting to perform the traditional betel and areca nut ritual. By using the betel nut ritual, the king communicates with the ancestors through local traditional speech, with the aim of providing optimal health and abundant garden produce to the people who bring the corn tribute. All guests and invitees receive betel nut as a symbol of customary power (30).

The culture is told in class, and then the teacher modifies the storyline to explain integers. Students understand negative numbers as “corn tribute debt” to the king, positive numbers as “corn tribute availability," and zero when the corn is "exhausted." Observations show that most students have been able to relate the concept of “debt” with negative numbers, although some still experience confusion in representing it symbolically. This stage succeeded in building students' intuitive understanding but also revealed the need for more concrete tools to reinforce it. Observations also showed that many students were interested in the story and were motivated to learn.

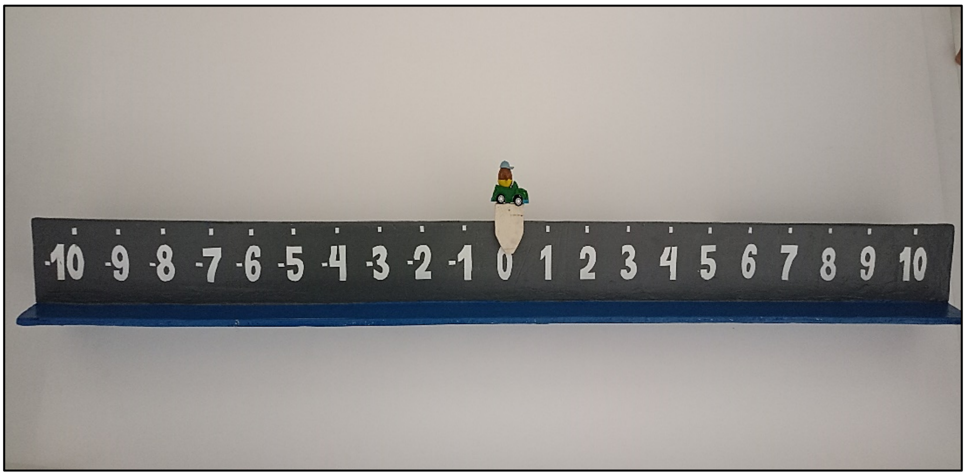

Figure 3: Integers Ruler

The "Integers Ruler" is a real teaching tool that students will use to learn in this phase of the model. This tool is made for students to practice putting numbers in order and adding and subtracting whole numbers. For instance, students move the piece to the right for positive numbers and to the left for negative numbers while they figure out how much more or less crops, they get. The results showed that most students could do simple math problems correctly, but they had trouble with bigger numbers because the props were too small. This finding shows that the Integer Ruler works well for early learning, but it needs to be changed to help with more advanced learning. The integer ruler display is as shown in Figure 3.

The model of phase provides opportunities for students to express their understanding independently through technological media, specifically interactive PowerPoint presentations (PPTs). The PPT includes a simulation video about the Batar Manaik tradition, an animation illustrating the whole number sorting process, and simulations for whole number addition and subtraction operations. This interactive media allows students to practice problems and solve them directly within the application. Additionally, the PPT is designed to acknowledge correct answers and provide motivational feedback for incorrect responses. Observation results indicate that students are motivated to utilize technology in their learning, which deepens their understanding of integers.

The next stage is the formal math phase, aimed at assessing students' ability to translate their contextual understanding into abstract mathematical notation. This stage is the most challenging, as students are introduced to new number symbols, including those for negative numbers. Here, students learn that a debt of three bundles of corn is represented by a specific symbol, the condition of having no corn is represented by another symbol, and the availability of ten bundles of corn in the warehouse is denoted by "10." For operations framed in a story context, an example might include the following: “Mr. Bertus owed five bundles of corn to the king and then paid back three bundles. How much does he still owe?” However, the Batar Manaik cultural story cannot explain all operational conditions; for instance, contextualizing certain operations culturally can be challenging. Consequently, the cultural context is primarily applicable for explaining simple operations, while more complex operations are addressed using formal mathematical concepts. Observation results showed that students are becoming accustomed to using formal mathematical symbols to solve problems related to number ordering and operations. Nevertheless, some students with lower initial abilities continue to struggle with understanding whole number operations. This finding serves as a basis for enhancing HLT 2.

Next was the numeracy stage. Students were given culture-based numeracy problems to solve. The results showed that most students were able to understand the concept of whole number sequences and operations formally, while the rest still needed the support of concrete props to solve the problem. There are some findings in this stage to be used as guidelines for improving HLT.

The next phase is the revision of HLT 2. Revision of HLT 2 was carried out based on the observation results at the pilot experiment stage. Some of the HLT improvements included:

(a) At the model for stage, the use of concrete media in the group needs guidance from the teacher, so the researcher decided to make the learning in the classroom use the team-teaching method,

(b) In the formal mathematics stage, more examples of problems and exercises so that students are familiar with mathematical symbols are needed. In addition, there needs to be student involvement to solve problems in front of the class so that students are more actively involved in learning

(c) At the numeracy stage, after students finish working on the LKM, each group is asked to present their answers in front of the class.

So that the teacher can monitor the improvement of students' numeracy skills directly. In addition, intense guidance needs to be done in small groups, because there are still many students who have difficulty solving problems at level 3. The results are HLT 3 shown in the Table 5.

Table 5: HLT 3

Learning Activities	Activities Goals	Thinking Conjectures	Anticipations
Informal Students observe the problem of debt in the Batar Manaik (Offerings to the King) culture of the Malaka people.	Students understand integers through the local cultural context of the Malaka district.	Students understand negative numbers as "corn debt" to the king, positive numbers as "corn availability," and zero when the corn is "used up."	Students may have difficulty understanding negative numbers in the given context, so the teacher anticipates this challenge by simulating the process of offering corn in the classroom.
Model of Concrete The teacher provides students with simulations of concrete props, including integers, rulers, and beads, and students work in groups to perform demonstrations using these materials while being accompanied by the teacher in a team-teaching approach.	Supporting students with kinaesthetic learning styles in the concrete operational stage is important for helping them understand the order and operations involved in adding and subtracting integers. Students can engage in activities that involve ordering integers and performing addition and subtraction operations on them.	Students grasp the concept of integer order through demonstrations using integer ruler props. They are also able to add and subtract integers with the help of integer bead props.	Students may not be able to understand the order and operations of the addition and subtraction of integers, so teachers need to guide discussions in small groups more intensely with the help of other co-teachers in Team Teaching.
Model for Semi-concrete Students in groups are given simulations of whole number addition and subtraction operations using technology-based learning media (PPT, iSpring Suite, and Canva).	Facilitate students with audio-visual learning styles to understand the operations of addition and subtraction of integers more deeply.	Students can understand whole number addition and subtraction operations more deeply through teacher explanation using technology-based learning media (PPT/Canva).	Students may need more time to understand integers addition and subtraction operations, so teachers collaborate to guide learners individually and in groups.
Formal Mathematics Students are introduced to mathematical symbols used in the addition and subtraction of integers. They engage in group practice problems related to these operations. Additionally, students have the opportunity to solve problems on the board.	Student's practice using the formal arithmetic symbols used in addition and subtraction of integers in groups after learning about them. This method also enhances their independence, self-assurance, and problem-solving abilities.	Students comprehend mathematical symbols and can accurately perform addition and subtraction operations involving integers using these symbols.	Students may not be ready with formal mathematical symbols, so students are allowed to reuse concrete props to solve the given problem.
Numeracy Students working in groups are given numeracy problems that incorporate the local cultural context of the Malaka district, focusing on number content at thinking process levels 1-3 in PISA.	Train students to solve numeracy problems in various levels of thinking processes.	Students are able to solve numeracy problems with the local cultural context of the Malaka district and number content in various levels of the thinking process.	Students may need more time to solve numeracy problems, so teachers collaborate to guide learners individually and in groups.

The learning goals of HLT number 3 are as follows:

(a) Students can explain the definition of integers,

(b) Students are able to sort integers,

(c) Students can perform addition and subtraction operations on integers and

(d) Students can apply addition and subtraction operations on integers to solve numerical problems.

Teaching Experiment

The teaching experiment phase included 30-Seventh grade junior high school students from

Malaka Regency and sought to assess the efficacy of the HLT 3-based learning design. The learning stages followed the five phases of HLT: the informal phase (Batar Manaik culture), the model for integers (ruler and integer beads), the interactive PPT model, formal mathematics, and numeracy stages. This implementation was done on a bigger scale to make sure the results were the same.

Informal Phase

Putting Batar Manaik Culture into Context. The procedure was the same as it was in the pilot experiment stage because the HLT didn't change. The lesson started with a video showing how the Batar Manaik culture works. The goal of this stage was for students to understand what integers are in the context of the Malaka district's culture. Students were supposed to understand that negative numbers meant "corn tribute debt" owed to the king, positive numbers meant "corn availability," and zero meant that corn was "exhausted." Students began to grasp integers, their members, and their order. This stage is a way to get used to more abstract ideas.

Figure 4: Group of Students Using Integer Ruler

You can use the integer ruler and integer beads to teach the order and basic operations of integers. These props help students learn about integer order and operations in a hands-on way. The integer ruler is a straight line with a zero point in the middle. It has pieces that can move to the right (for positive numbers) or to the left (for negative numbers). Students can learn to order numbers by looking at their relationships. For example, students can see that 1 is greater than 0 because -1 is to the left of 0 and 1 is to the right of 0. By looking at where the pieces are, students can tell that the numbers on the left are smaller and the numbers on the right are bigger.

When students do integer operations, they move the piece on the integer ruler according to the sign of the operation. For instance, they can begin at point "A" and move the piece six steps to the right until it reaches point "G." Also, when you subtract negative numbers (which is the same as adding positive numbers), the piece starts over at "A" and moves to the right. This tool can also show how to subtract positive numbers by moving the piece 5 steps to the left until it is in its new place. The student process uses an integer ruler as shown in Figure 4.

Integer beads help you learn by giving you a physical way to see the numbers with beads of two colours (for example, yellow for negative and green for positive). The integers beads display is as shown in Figure 5. For the addition operation, students take 4 green beads and 2 yellow beads. They then pair each yellow bead with a green bead (because 1 and -1 cancel each other out). There are still two green beads left, so the answer is two.

Figure 5: Integers Beads

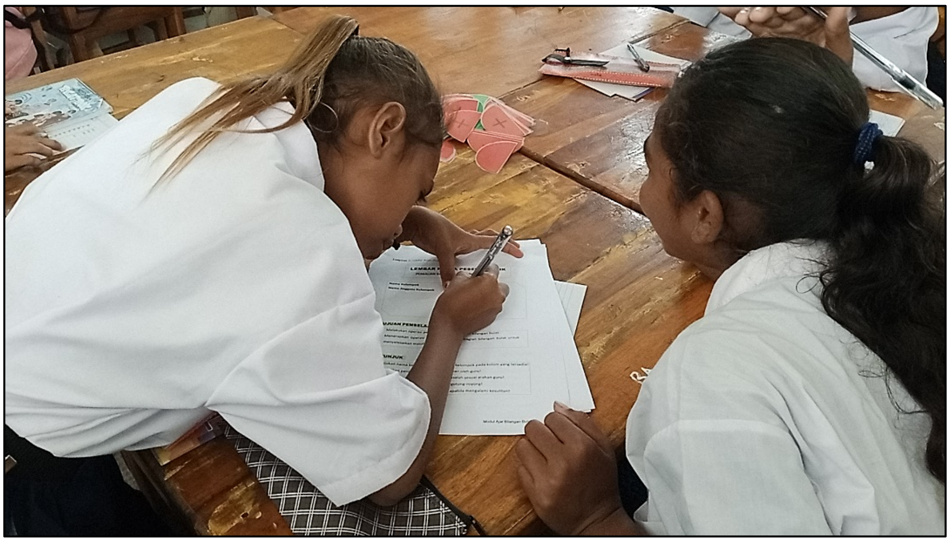

Figure 6: Students Use Integer Beads to Solve Numeracy Problems

Students use the idea that subtracting a negative is the same as adding a positive when they do subtraction problems like this one. For example, they add 1 green bead to the 3 green beads they already have, which gives them 4 green beads. The Integer Ruler and Integer Beads work together to help students understand by using visual-spatial (number line) and kinaesthetic (moving beads) methods. This method follows the theory of enactive-iconic-symbolic learning, which says that students first learn by doing things (enactive), then by seeing things (iconic), and finally by using formal mathematical symbols (symbolic) (31). With this tool, students memorize the rules of operation and understand the conceptual meaning behind whole number calculations. The process of students using integer beads to solve numeracy problems is shown in Figure 6.

Students can use interactive PowerPoint media to learn about integers and show what they know. They are encouraged to share what they know and think on their own. The goal of this stage of learning is to show how students naturally think before they learn formal notation. The interactive PowerPoint is set up so that students can learn about positive and negative numbers by doing drag-and-drop activities, watching animations, and taking quizzes that are like games and are based on real-life situations. This method lets students learn about numbers by trying things out and making mistakes, and it also gives them feedback right away when they do. The formal mathematics stage is the last step in learning about integers. At this point, students will use what they learned about abstract mathematical notation during the informal, model of, and model for stages. Students must use standard mathematical symbols to do whole number operations like addition, subtraction, multiplication, and division. They can't use physical props or cultural contexts to help them. The goal of learning is to learn the right way to do math and how to use the rules for whole number operations, like "multiplying two negative numbers gives you a positive number" and "subtracting negative numbers is the same as adding positive numbers."

Retrospective Analysis

Based on the framework for analyzing teaching experiments, the analysis of the Hypothetical Learning Trajectory (HLT 3) for the proposed design demonstrated effectiveness and was successfully transformed into a Local Instructional Theory (LIT) relevant to the context of Malaka District.

Based on Table 6, an analysis of pretest and posttest data from 30 students shows the effectiveness of numeracy education rooted in local culture. The average score of the students went up a lot, from 52.4 in the pretest to 78.6 in the posttest, with an N-gain of 0.62, which is considered a "medium" category (32). This "medium" category means that students are successfully linking concrete knowledge from their culture with the abstract idea of integers. Also, 73% of the students met the Minimum Completion Criteria. This feat means that they could solve problems in context, like figuring out how to analyze Malacca weaving patterns and the Batar Manaik debt-receivable system. This achievement demonstrates that students can memorize formulas and apply their knowledge to solve personally significant problems

Table 6: Design Experiment Analysis Results

Aspect	Result/Value	Description
Learning Trajectory Outcome	HLT 3 → LIT	The Hypothetical Learning Trajectory (HLT 3) proved effective and was successfully developed into a Local Instructional Theory (LIT) tailored to the context of Malaka Regency.
Average Pre-test Score	52.4 (SD = 8.7)	Baseline ability before intervention.
Average Post-test Score	78.6 (SD = 6.9)	Ability after intervention; shows a significant increase.
N-Gain Score	0.62	Medium effectiveness category (Hake's N-gains criteria).
Students Achieving PISA Level Numeracy 1-3	73% (22 out of 30 students)	Majority of students reached functional numeracy levels based on PISA framework.
Cultural Context Problem-solving Ability	Demonstrated	Students are able to solve contextual problems based on local culture.

Qualitative data from interviews and observations backs up this quantitative success. It was noted that 85% of students actively used the "Integer Ruler" teaching tool and took part in cultural simulations, which made the learning environment more interactive and real. Interviews with six students revealed a significant emotional aspect: reduced math anxiety. One student said, "I understood the debt story in the Batar Manaik tradition, and it helped me understand integers and how to work with them better." This report shows that teaching math in a way that connects to students' cultural backgrounds can change how they think about it from something scary and abstract to something useful and understandable. The results of this study align with previous research that highlights the importance of culturally responsive pedagogy. Using local knowledge can help students understand ideas better and use math skills better. It can also make learning more fun and welcoming by lowering anxiety. This learning model shows how well the national curriculum can be changed to fit the needs of different cultures, which makes learning more meaningful. This success makes it possible to use similar methods in other math resources or in places where people from different cultures live together.

It is important to emphasize that the mean score, completion rate, and N-gain are intended only to help illustrate the data and improve the design of this study. These figures are not intended to be used as generalizations to the larger population. The main goal is to assess the intervention plan's efficacy so it can be improved. The post-test results showed that 27% of students still did not meet the minimum completion criteria. Based on interviews with several of these students, they complained that they still had difficulty understanding numeracy problems related to addition and multiplication of negative and positive numbers. These findings provided valuable insights for improving the HLT, specifically in the fifth stage, which focuses on numeracy. In numeracy problem-solving exercises, practice questions for students with low abilities were more intense, and the variety of mathematical problems should begin with easy problems and then move on to more complex ones.

The data triangulation process, which included test results, observations, and interviews, showed that the Hypothetical Learning Trajectory (HLT) worked to reach three main goals. First, there was a significant improvement in students' ability to translate culturally based contextual problems, such as the debt system in the Batar Manaik tradition, into formal mathematical symbols. Second, this method worked because it helped students understand operations with negative numbers instead of just memorizing them. This is because they thought of "debt" in a concrete way. Third, students' learning motivation increased dramatically because the learning felt relevant to their lives and culture, making mathematics more meaningful and enjoyable.

This successful implementation enabled the transformation of the hypothetical HLT into a tested and applicable Local Instruction Theory (LIT). This transformation was made possible by a learning design that carefully integrated local culture as a context for triggering thinking schemes and technology, such as the Integer Ruler teaching aid, as a bridge to mathematical abstraction. For educators, the resulting LIT provides a structured guideline for teaching integers using an ethnomathematics approach, complete with pedagogical anticipation of student responses. At the policy level, these findings support the implementation of the Independent Curriculum by providing concrete examples of how local content can be integrated without losing the essence of national competencies, and also paving the way for the development of local learning theories across a variety of topics and cultural contexts.

Discussion

This research successfully designed a HLT aimed at improving students' numeracy skills in number content. The HLT developed in this study consists of five stages that are structured hierarchically and systematically. These five stages include: (a) the informal stage, (b) the model of concrete stage, (c) the model for semi-concrete stage, (d) the formal mathematics stage, and (e) the numeracy stage. Each stage in this learning trajectory is not standalone but rather interconnected and structurally supportive of one another to gradually and continuously build students' understanding.

The informal stage serves as the initial foundation that activates students' everyday knowledge and experiences as a starting point for learning. Next, the model of concrete stage facilitates students in representing informal situations into concrete models that can be directly manipulated. The model for semi-concrete stage then serves as a bridge that transforms concrete representations into semi-abstract forms such as images or diagrams. At the formal mathematics stage, students are introduced to standard symbols, notation, and mathematical procedures as the culmination of the abstraction process. Finally, the stage of numeracy becomes the ultimate goal that reintegrates formal understanding into real-life contexts, enabling students to apply numerical concepts functionally in various practical situations.

The five stages as a whole form a coherent and progressive unity, where each stage supports the achievement of the next stage in a sustainable manner. This systematic learning trajectory is designed to ensure that the improvement of students' numeracy skills occurs optimally thru a meaningful, gradual, and developmentally appropriate learning process.

Before producing the final design ready for implementation, the HLT in this study has undergone a series of rigorous testing phases to ensure its validity and effectiveness. This process generally involves an iterative design research cycle, starting with expert judgment to assess the content and construct validity of the initial HLT design. Subsequently, limited trials (field practice) are conducted to observe the feasibility of the learning stages and student responses.

A retrospective analysis of the implementation of HLT 3 provided substantial empirical evidence regarding the effectiveness of the Malaka local culture-based learning design, which integrates technology to enhance students' numeracy skills in number content. The conversion of HLT 3 into LIT illustrates that the designed learning model succeeded not only in theory but was also empirically validated through practical classroom trials. This success stems from a systematic design research process in which each learning cycle is carefully examined to refine the student learning path until the optimal version of HLT is achieved, ultimately resulting in LIT. This aligns with previous research indicating that, in educational design research, producing an LIT necessitates repeated testing, akin to iteration, to ensure the design meets criteria for validity, practicality, and effectiveness (33).

The quantitative data analysis in this study indicates a significant enhancement in students' numeracy skills, evidenced by the rise in average scores from 52.4 (SD=8.7) on the pretest to 78.6 (SD=6.9) on the posttest. This improvement led to an N-gain of 0.62, which is a moderate level of improvement. It is vital to know that even if the N-gain is technically at a moderate level, this accomplishment is noteworthy and should be praised given the pupils' initial knowledge. Prior knowledge is a strong predictor of students' mathematical literacy achievement, with those possessing a weak foundational understanding need additional work to attain substantial growth (34). In this case, a pretest score of 52.4 shows that students' knowledge is at a level that needs a lot of help. The fact that their score went up by 26.2 points and their N-gain was 0.62 shows that the learning intervention worked.

More important than just an increase in average scores is the achievement percentage of students in numerical literacy based on the PISA framework, where 73% of students managed to reach levels 1-3. This achievement has deeper pedagogical significance because it shows that the majority of students are not just improving their test scores, but are truly developing numeracy competencies that are internationally recognized. The improvement in students' numeracy skills is not only reflected in test scores, but more crucially, in how students can achieve competency levels that meet international standards such as PISA. Student-centered teaching methods can significantly improve the achievement of higher numeracy skills (35).

Thus, the combination of an N-gain of 0.62 (medium category) and 73% of students achieving levels 1–3 in PISA numerical literacy indicates the success of the learning intervention, which not only quantitatively improved test scores but, more importantly, developed globally recognized functional numeracy competencies. This aligns with previous studies that emphasize the significant impact of teachers' numeracy teaching skills on student performance, and meaningful improvement in numeracy competencies occurs when students can reach ability levels applicable in real-life contexts according to international standards (36).

The strength of this research also comes in the fact that it uses both quantitative and qualitative data to support its findings. Observations that recorded 85% of students actively participating using concrete teaching aids show that this approach can promote interactive and student-centered learning. Interview data also revealed a significant emotional dimension: a reduction in math anxiety. Students' claims about their understanding of integers through debt narratives in the Batar Manaik tradition indicate that substantial learning occurs when content is connected to their personal experiences and cultural values. This supports previous studies that show that emotional factors such as motivation and self-confidence are very important for learning mathematics well (37, 38).

The conversion of HLT to LIT provides dual contributions, both theoretically and practically. Theoretically, this research enhances the field of ethnomathematics by providing a concrete illustration of how local learning theories are developed in the specific context of Malaka. In practice, the resulting LIT is a structured guide for teachers on how to teach integers. It also includes what they think their students will say. This work is significant because educators often face challenges in transforming the standardized national curriculum into contextually relevant teaching methods. With LIT, teachers can see how the lesson will unfold, anticipate the problems students will face, and use appropriate intervention strategies, such as differentiated instruction or scaffolding techniques, to better support their students' learning needs (39).

The findings of this study have strategic implications for educational policy, particularly concerning curriculum implementation. The successful establishment of a local culture-based LIT in Malaka illustrates that schools can adapt their pedagogical methods to meet local needs while maintaining compliance with national standards. The LIT can be applied in different regions possessing unique local knowledge, resulting in diverse learning methods that remain aligned with national educational objectives (40). It is recommended to undertake further research to assess the effectiveness of this LIT on a broader scale, to modify it for other mathematical disciplines, and to explore the integration of advanced digital technologies to improve the ethnomathematics learning experience.

Conclusion

Based on a retrospective analysis and discussion, it can be concluded that implementing a Hypothetical Learning Trajectory (HLT 3) for teaching integers, rooted in the local culture of Malaka Regency, has proven effective and has successfully transformed into an applicable Local Instruction Theory (LIT). This effectiveness is evidenced by a notable increase in students' numeracy scores, rising from 52.4 to 78.6, with an N-gain of 0.62. Additionally, 73% of students achieved PISA numeracy levels 1–3 and were able to solve contextual problems, such as analysing Malaka weaving patterns and the Batar Manaik system. The triangulation of quantitative and qualitative data confirms that the ethnomathematics approach not only enhances conceptual understanding and mathematical application skills but also alleviates anxiety and boosts students' motivation to learn by connecting the material to their cultural experiences. This study offers a theoretical contribution by enriching ethnomathematics through contextual LIT and provides a practical contribution as a structured guideline for teachers to implement a mathematics curriculum that adapts to local wisdom. This opens up possibilities for replication in various regions, each with its unique cultural richness.

While we can consider the research findings successful, we must acknowledge several limitations. First, the cultural context of Malaka Regency limited this study, necessitating further adaptation when generalizing the findings to other cultural contexts. Second, the small number of students and short duration of the intervention may not demonstrate optimal effectiveness in improving students' numeracy skills. Third, this study only examined integers, raising questions about whether similar success rates could be achieved in other areas of mathematics, such as geometry, algebra, or statistics.

These limitations pave the way for additional research. Subsequent researchers may replicate this study in areas characterized by distinct local wisdom. Long-term studies are also needed to determine whether this approach will have long-term effects on students' academic performance and numeracy skills improvement. Additional research could explore the development of more comprehensive assessment tools to evaluate not only cognitive skills but also affective dimensions, including students' cultural identity and appreciation of mathematics as an integral part of their culture.

Abbreviations

HLT: Hypothetical Learning Trajectory, LIT: Local Instructional Theory, PISA: Programme for International Student Assessment, PPT: Microsoft Power Point Presentation.

Acknowledgement

Thanks are given to all parties involved in this research, especially the entire academic community at Fahiluka State Middle School, Malaka Regency.

Author Contributions

Yohanes Hariaman Nada: prepared articles, coordinated the research process, coordinated the development of research instruments, Siprianus Suban Garak: created a HLT, developed technology-based learning media, quantitative data analysis, Wara Sabon Dominikus: assisted with the development of a HLT, developed local culture-based learning media, qualitative data analysis, Damianus Dao Samo: assisted with the development of technology-based learning media, quantitative data analysis, Aleksius Madu: assisted with the development of local culture-based learning media, assisted with the development of numeracy literacy evaluation instruments, Bakher Nenotaek: implemented the media validation process, validation data analysis.

Conflict of Interest

There is no conflict of interest whatsoever in this research.

Data Availability

The corresponding author can provide the data supporting this research upon reasonable request.

Declaration of Generative AI And AI Assisted Technologies in the Writing Process

There is no use of Generative AI and AI-assisted technology in the writing process of this article, the entire contents of this article are the result of scientific research.

Ethics approval

This research was conducted with the permission of the principal of the school where the research took place through letter number 472/UN15.13.7/KP/2025. All participants provided informed consent prior to their participation in the study.

Funding

All the needs for implementing this research are funded by the DIPA funds of Nusa Cendana University in 2025.

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How to Cite: Nada YH, Garak SS, Dominikus WS, Samo DD, Madu A, Nenotaek B. Local Culture-based Learning Design with Technology Integration to Improve Students' Numeracy Skills on Number Content. Int Res J Multidiscip Scope. 2026;7(2):916-932. DOI: 10.47857/irjms. 2026.v07i02.010196