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Design Principles for Low-Tech, High-Impact Mathematics Teaching Tools in Resource-Limited Nigerian Classrooms

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Abstract

Systematic infrastructural challenges in Nigerian education, especially in public institutions and rural areas, may often hinder the adoption of high-tech instructional software. These include unstable power systems, a lack of digital technologies, and high internet pricing. The study examines the development, production, and pedagogical use of low-tech, high-impact (LTHI) mathematics instructional resources that are particularly relevant for low-resource Nigerian classrooms. The concrete manipulatives use locally acquired, culturally relevant, and repurposed municipal waste products (e.g., bottle caps, bamboo, recycled plastics, and traditional fabrics) to bridge the important gap between abstract mathematical ideas and physical cognitive understanding. This study presents a holistic design paradigm that addresses localised structural durability, affordability, cultural synthesis, and cognitive alignment (mathematical integrity). It also shows how LTHI tools help active learning, improve memory retention, reduce widespread math anxiety, and make quality STEM education accessible without digital infrastructure by using localised context analysis, empirical performance reviews, and stepwise structural prototypes, such as a hanger-based game adaptation. High-impact maths education doesn't require a high-tech solution. Deliberately constructed within the ADCC framework, low-tech instructional resources offer a highly successful, climate-resilient, and socioeconomically equitable alternative that encourages deep conceptual mastery in resource-constrained contexts. Among other recommendations, it advised that public school clusters inside LGAs should construct local "Math-Labs" for co-creating, storing, and exchanging durable low-tech high-impact (LTHI) instruments among adjacent institutions. Ultimately, this study provides curriculum designers and teachers with preparation programs and realistic techniques to extend long-lasting, economical educational efforts throughout the country.

Keywords: Low-Tech Learning, Mathematics Manipulatives, Resource-Limited Classrooms, ADCC Framework
Conceptual Retention.

Introduction

In the global discourse on educational technology, artificial intelligence, virtual reality, and digitalisation are heavily favoured. Yet for millions of kids in Nigeria, this digital promise remains mostly out of reach. Many public schools are overloaded with classrooms (teacher-to-student ratio of 1:60-100), old buildings, and a complete lack of electricity due to acute shortages of basic infrastructure. Many local government secondary schools are still critically short of cutting-edge resources such as ICT equipment, projectors, computers, and specialist software (Onum, 2026). Costly electronic devices frequently end up as "white elephants"- hardware sitting unused in locked-up buildings due to

power cuts, a dearth of technical support, or fear of theft when they are placed in these settings by government or non-governmental organisations that lack continuing support.

These discrepancies provide a specific hazard to Nigerian mathematics education. Mathematics is an abstract subject, and students need concrete representations to construct good mental models. Teaching in Nigerian public schools, without manipulative aids, often reverts to a rigorous “chalk-and-talk” technique that emphasises rote memorisation and procedural drills. This educational failure is evident in poor performances on national examinations such as the West African Senior School Certificate Examination (WASSCE) and the Unified Tertiary Matriculation Examination (UTME) (Ejiofor-Chima, 2026). Research shows that teacher-centered teaching approaches that stress memorisation rather than conceptual understanding and problem-solving are still prevalent in Nigerian maths classrooms (Yusha'u, 2015). This traditional method often depicts mathematics as hard, distant, and unrelated to students’ daily life. Consequently, many students develop unfavourable attitudes toward mathematics, low motivation, and concern about the subject.

According to Onyelere et al. (2025) (p. 1), educational technology has revolutionised classroom practices around the world through the use of computers, tablets, interactive whiteboards, virtual simulations, and online learning platforms. But because of budgetary and infrastructural constraints, many Nigerian schools may not have access to this state-of-the-art technology. Thus, there is an increasing desire for sustainable and context-sensitive solutions to improve mathematics instruction with less reliance on expensive technologies. Such a route is the creation and dissemination of low-tech, high-impact resources for maths instruction.

These teaching tactics require limited use of digital infrastructure and greatly enhance student engagement, conceptual understanding, and classroom interaction. Examples include locally created manipulatives, cardboard geometric models, flash cards, bottle-top counters, number cards, fraction strips, charts, ropes for measurement tasks, and reusable activity boards. Afolabi and Adeleke (2010) explain that the success of educational resources is more dependent on the pedagogical relevance, accessibility, conceptual appropriateness, and ability to stimulate meaningful learning than on technological complexity. Low-tech teaching aids, when correctly conceived, can offer scalable and affordable solutions to problems in mathematics education in resource-poor settings. The article advocates for a paradigm shift to Low-Tech, High-Impact (LTHI) pedagogy that responds to the socio-cultural and economic realities of Nigeria. LTHI technologies are scalable, practical, low-cost educational solutions that maximise cognitive engagement while minimising infrastructural and financial footprints.

Clarification of Terms

Low-Tech Teaching Aids: Low-tech educational resources and instructional materials are tools for instruction that need little or no advanced technical infrastructure to operate. Generally, they are cheap, easy to manufacture locally, sturdy, and flexible enough to be suitable for different classroom or school settings (Bature & Atweh, 2019). The technologies or solutions are not aimed at digital automation but rather at student engagement and physical involvement. Some examples are: Number cards, paper foldables, fraction strips, a locally built abacus, geometric models, flashcards, counting objects, and mathematical manipulatives. **High-Impact Tools for Teaching:** High-impact tools for teaching are those instructional resources that greatly enhance student knowledge, retention, involvement, engagement, and academic achievement. A big part of their success comes from their capacity to foster conceptual understanding and active learning. Beatty et al. (2005). **Resource-Limited Classrooms:** Resource-limited classrooms are characterised by underfunding, poor infrastructure, lack of teaching materials, poor technology facilities, overcrowding, and inadequate ways to assist instructors (Ojimba, 2012).

Theoretical Framework and the Nigerian Context

Based on Nigerian classroom dynamics, the effectiveness of low-tech, high-impact (LTHI) instruments, according to basic theories of cognitive psychology, is: Bruner’s Modes of Representation: Enactive-Iconic-Symbolic (EIS) Learning is described as proceeding from symbolic (abstract language and notation) to iconic (visual images or diagrams) to enactive (hands-on action with objects) by Bruner (1966). Children can physically control quantities, shapes, and connections with low-tech devices that operationalise the enactive stage before they are required to manipulate numerals and operators. The physical manipulatives can be used by Nigerian learners to physically

manipulate the variables before representing them as algebraic symbols on a slate or whiteboard. This is the key enactive stage in an environment where textbooks are scarce.

Embodied Cognition: This perspective emphasises the role of the body’s connection with the physical world in cognitive processes. Physical handling of mathematical objects activates spatial-motor pathways leading to deeper mental encoding. Concrete materials help externalise abstract structures like amount, equivalency, and value place through organised tactile contact when systematically embedded and not used as an afterthought (Rasheed, 2026).

Culturally Responsive Pedagogy (CRP)/Ethnomathematics: Mathematical reasoning is culturally entrenched (D’Ambrosio, 2001; Umar et al., 2019). Local customs like weaving, trading, counting grain, and pouring bricks should be made into helpful instruments – not as strange instances but as the basis of mathematical thinking. Technology that reflects a child’s life outside of school minimises cognitive burden and reinforces cultural identity. In Nigeria, a country of more than 250 different ethnic groups such as Hausa, Igbo and Yoruba, mathematics is sometimes viewed as an alien notion. LTHI instruments are integrated with indigenous games, textiles and ordinary market realities to recast maths as an accessible, local human activity.

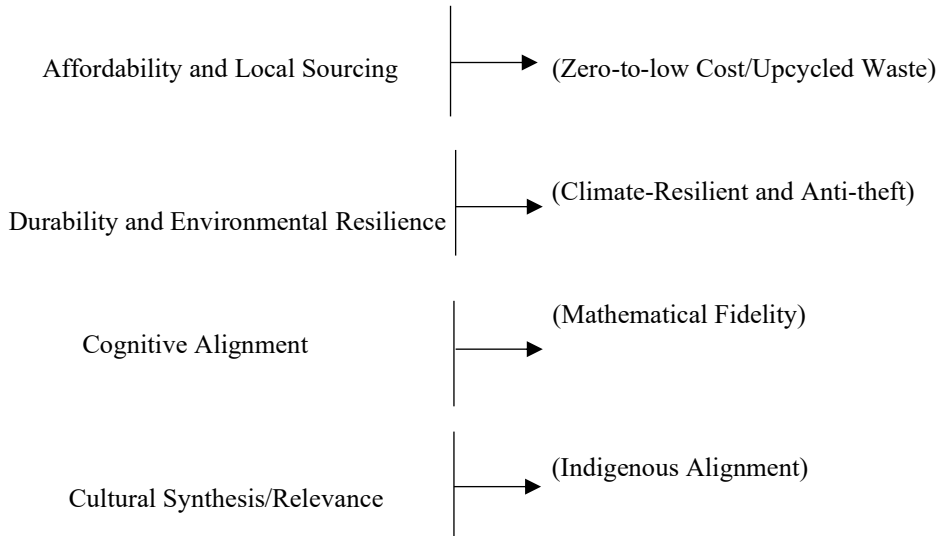
Teaching at the Right Level (TaRL): This learning strategy focuses on learner-centred instruction and low-cost, basic instruments to develop fundamental reading and numeracy skills. According to UNESCO (2021), the Kano Literacy and Numeracy Accelerator Initiative improved mathematics learning outcomes with scalable, low-resource interventions.

Participatory design and frugal innovation: Frugal innovation is about maximising value from a minimum number of resources and highlights simplicity, affordability, and reuse. Participatory education means teachers and students are co-designers of tools, not passive consumers.

Discussion

Design Principles for Low-tech, High-Impact (LTHI) Mathematics Tools in Nigeria. The ADCC Framework (Affordability, Durability, Cognitive Alignment, Cultural Synthesis) is a collection of foundational principles that designers and educators must adhere to in an effort to ensure that low-tech tools are both scalable and rigorous in Nigerian classrooms.

ADCC DESIGN FRAMEWORK



1. **Affordability and Local Sourcing (Zero-to-Low Cost).** The materials used to produce tools must be very cheap, free, or recycled from municipal garbage. This removes the need for unpredictable government cash allotments or outside assistance. Math teaching materials should be affordable enough that communities, teachers, and schools can

provide them without breaking the bank. Inexpensive teaching instruments can be created from recycled materials, rejected products, locally sourced goods, and community resources. Inexpensive materials promote scalability and sustainability. Recommended Nigerian Materials: Empty sachet water bags (also known as 'pure water' nylon), shells of palm kernels, bamboo slats, used plastic or metal bottle caps (also known as 'crown corks'), cardboard or cartons for geometric shapes, ropes for measuring exercises, sticks for math demonstrations, and leftover textiles from regional tailors (Lace, Kampala, or Ankara). Design Requirement: The object should be easily reproducible by a teacher or student with simple tools such as scissors, local glues, or a pocket knife.

2. Environmental Resistance and Durability (Localised). Instructional materials should be durable and reusable since many Nigerian schools do not have the capacity to renew their instructional resources periodically (Afolabi & Adeleke, 2010). The weather in Nigerian classrooms is notoriously extreme, from the heat and dust of the northern harmattan season to the intense humidity and rainfall of the southern coast. Moreover, there is the risk of objects being stolen, spoilt, or infested by insects as public schools do not usually have safe lockups (Iji et al., 2014). The tools have to be sturdy (for example, counters made of baked clay rather than paper) and able to be repaired by students using local techniques (re-tying, re-baking, re-gluing using cassava paste). Design Requirement: Tools should be made to endure dust, termites, and dampness/moisture. Don't use delicate joints or small pieces that are easily lost. As a general rule, a lost component (e.g., a counter in a probability kit) should be immediately replaceable by a common local equivalent (e.g., a bottle cap or a uniform pebble). Other design considerations: laminated materials, multi-use functionality, robust cardboard or wooden structures, protective storage method. Durable instruments reduce long-term education costs.

3. Cognitive Congruity and Mathematical Fidelity. A tool must adequately depict the underlying mathematical structure, without misconceptions or cognitive static (unnecessary aesthetic distractions). Research work carried out in Nigerian secondary schools has indicated that systematic application of improvised teaching materials reduces the cognitive abstractness of geometric and algebraic domains, which directly increases students' retention and achievement scores in post-tests (Altine, 2026; Iji et al., 2014). The mathematical laws must be mirrored in the physical restrictions of the tool. To align two strips exactly with one strip, for instance, a low-tech fraction strip of cardboard, has to be measured and cut. Incorrect physical measurements result in arithmetic mistakes and mental disorientation.

4. Cultural Synthesis and Contextual Significance: The teaching materials used should reflect students' daily experiences and their social and cultural surroundings. Students are more motivated, comprehend, and interact more when the content is relevant to them (D'Ambrosio, 2001). Mathematics should be made relevant by the utilisation of indigenous board games, everyday Nigerian life, and local socio-economic activities such as market measurements and petty trade. Use market transactions to teach arithmetic; use local farming activities to teach measurement; use indigenous patterns to teach symmetry; use local currencies to teach financial mathematics; share kolanut; fill water pots; teach fractions using a shared puff-puff (fried dough ball) or a gari (cassava flakes) measuring tin, not a fraction pie chart. Indigenous-relevant tools make maths more meaningful and less abstract. Design Requirement: Incorporate familiar cultural elements. When abstract geometry is taught using traditional board games for arithmetic or local textile geometric patterns to teach symmetry, it becomes a concrete cultural artefact.

Other Design Principles for Nigerian low-tech, high-impact (LTHI) Mathematics Tools include:

1. Interactivity and Learner Engagement: Mathematics learning is more successful when students actively participate in educational activities than when they passively absorb the knowledge (Beatty et al., 2005). Low-tech instructional resources are designed to promote inquiry, manipulation, learning by Discovery, cooperation with peers, group activities, and problem-solving. Interactive learning helps learners comprehend and remember concepts better.
2. Flexibility and adaptability: An effective instructional instrument should be able to accommodate many mathematical tools at different educational levels (Bature & Atweh, 2019). For example, counters can be useful in teaching statistics, probability, and arithmetic. Fraction strips can be used to support algebraic reasoning, ratios, percentages, and fractions. Adaptable tools keep costs down and maximise educational value.

3. **Universal Design and Inclusivity:** Instructional resources should be accessible to all students, including those with impairments. Teaching materials should promote equal participation, a requirement that is important for inclusive education (UNESCO, 2021). The features of inclusive design can include: visible large print; tactile materials; multisensory interaction; resources compatible with Braille; contexts that are responsive to gender; equitable learning opportunities. Inclusive tools are tools that support mathematics.
4. **Teachers-Friendly Design:** Teachers in resource-constrained schools often encounter heavy workloads and a lack of professional assistance. Therefore, instructional resources ought to be easy to develop, use, and manage (Yusha'u, 2015). Teacher-friendly resources should: Meet the goals of the curriculum; Give clear instructions on how they are to be used; Require little prep work; and cater for large classrooms. The easier it is to implement, the more likely it is to be adopted in the classroom.
5. **Community Engagement and Sustainability:** Sustainable instructional innovation needs active engagement from local communities, parents, craftsmen, and educational stakeholders (Ojimba, 2012). Community participation improves sustainability, cultural appropriateness, cost-effectiveness, and ownership of resources in the long run. Local instructional resources foster creativity and innovation among students and teachers.
6. **Learners' Interactivity and Engagement:** Mathematics learning is more successful when students actively participate in educational activities rather than passively collecting knowledge (Beatty et al., 2005). Low-tech educational resources should encourage inquiry, manipulation, discovery learning, peer cooperation, group activities, and problem-solving. Interactive learning encourages better understanding and memory of concepts.
7. **Ease of Use and Simplicity:** Low-tech educational resources should be easy to use for both teachers and students. Teachers with minimal expertise may be hesitant to employ complicated instructional resources in the classroom (Yusha'u, 2015). Basic tools cut down on prep time. Enhance classroom management, stimulate low engagement, and increase broader participation. Simplicity is also easier to maintain.

Examples of Low Tech, High Impact Mathematics Tools

1. **Manipulative:** Conceptual knowledge is enhanced by hands-on manipulation. Learners understand better by using manipulatives such as pebbles, beads, counters, bottle tops, and sticks:
 - Probability
 - Place values
 - Counting
 - Arithmetic
 - Fractions
2. **Visual and Chart Displays:** Virtual learning tools can improve memory retention and understanding. Posters and charts increase knowledge of the concepts visually. They can display:
 - Worked examples
 - Graphs
 - Mathematical expressions
 - Symbols
 - Processes
3. **Geometric Models:** These instruments diminish the abstraction of the teaching of geometry. Locally fabricated geometric solids of wood, clay, or cardboard help students visualise:
 - Angles
 - Symmetries
 - Relationships in space
 - Surface area
 - Amount
4. **Mathematics Games:** The games aid in improving problem-solving and cooperative learning. Mathematics games have a lower cost, and they enhance students' enthusiasm and classroom involvement. For instance:
 - Counting games of Indigenous peoples

- Games of dice
- Sudoku
- Mathematical puzzles
- Playing cards

5. Lines of numbers and Fraction Strips: They also improve the visual thinking skills of kids. Fraction strips and numbers help to understand:
 - Operations in mathematics
 - Ratios of valuation
 - Totals
 - Decimalised
 - Fraction

The table below maps the physical characteristics of successfully deployed and implemented low-tech, high-impact (LTHI) tools to certain Nigerian curriculum needs.

Table 1: Taxonomy of High-Impact low-tech, high-impact (LTHI) Mathematics Tools for Nigeria

Tool Name	Local Materials Required	Target Mathematical Domain	Cognitive/Pedagogical Function
The Ayo Olopon / Okwe Probability Board	Palm kernel shells or seeds, Traditional wooden Ayo board (or egg crates as a proxy).	Sequence tracking, basic arithmetic, Combinatorics, and probability.	Converts a culturally ubiquitous game into a physical sample space for calculating permutations, ratios, and experimental probabilities.
Geometric Tessellators of Ankara	Scrap Ankara or Adire fabrics with geometric motifs, discarded rigid cardboard box backing.	Tessellations, Geometry, transformations (rotation, reflection, translation).	Allows students to physically isolate, trace, and manipulate repeating geometric units, bridging cultural art and mathematical theorems.
Pure-Water Bag Fraction Walls	colored markers, cleaned, cut sachet water nylons ("pure water" bags), uniform cardboard strips.	percentages, fractions, decimals, ratios.	Slip-pocket systems where students insert varying lengths of cardboard to visually and tactilely compare equivalent fractions (e.g., seeing why $\frac{2}{4} = \frac{1}{2}$).
Hanger & Plastic Cup Algebraic Balance	Plastic coat hanger, nylon twin string, two identical empty tomato paste tins or plastic cups, and bottle caps as uniform weights.	isolating variables, simple linear algebraic equations.	Physically operationalizes the concept of algebraic equilibrium: whatever operation is performed on the left expression must be mirrored on the right to keep the scale level.

Table 2 shows three proven tools, their materials, mathematical aims, and design reasoning.

Table 2: Exemplar Tools: From Principle to Practice

Tool Name	Materials (Nigeria-sourced)	Key Mathematical Concepts (NERDC Curriculum)	Design Applied	Principles
Cassava Fraction Board	Old knife or string for making lines, a rectangular slab of sun-dried cassava stem, or thick cardboard.	Simple addition of fractions, unit fractions ($\frac{1}{2}$, $\frac{1}{24}$, $\frac{1}{8}$), Equivalence ($\frac{1}{2} = \frac{2}{24}$).	Teacher co-constructed; collaborative pairs shared board; resonance- cassava processing is common.	
Market-Stall Array	Bottle caps or pebbles as “goods,” egg cartons, or a ground grid drawn in dirt.	Area model of multiplication (Grade 5 pupils), Multiplication as arrays (Grade 4 pupils), Commutative property ($3 \times 4 = 4 \times 3$).	Zero-cost, designed for groups, context: market trading	
Bottle-Top Abacus	Scrap cardboard or plywood, 50 plastic bottle caps, and used shoelace or fishing line.	Addition/subtraction with regrouping (Grade 3-4 pupils), Place value: Units/Tens/Hundreds (Grade 2-3 pupils), Counting (K-1 pupils)	Durable, Reusable Zero-tech, Local materiality.	

Implementation Methodology and Case Prototypes

Prototype 1: The Linear Equation Hanger Balance

The low-tech, high-impact (LTHI) hanger balance is an elegant solution to the abstract obstacle of teaching equations without digital software. Construction: Suspend a standard plastic clothes hanger from a classroom nail or a teacher's hand. Strings are hung from both ends to two similar plastic cups (or clean tin cans). Mathematical Application: An opaque cup designated x holds an unknown number of bottle tops. Constants (b and c) are loose bottle caps. Thus, to solve $2x + 3 = 11$, students put two “ x ” cups and 3 loose bottle caps in the left basket and put 11 loose bottle caps in the right basket. The Enactive Action: The student takes 3 loose caps from both sides to keep it balanced, then splits the other 8 caps in the right basket evenly between both “ x ” cups and finds out that $x = 4$ physically. Prototype 2: Using paper folding to teach fractions and spatial geometry. Paper-folding, which employs old newspapers, fliers, or commercial publications, solves a major difficulty in primary and lower basic education. Application of Mathematics: Teaching fractions without using concrete board notation can often impede the student's ability to understand parts of a whole. Students divide a uniform sheet physically by using paper-folding processes to look for related fractions and spatial relationships. Empirical Outcomes: Empirical findings on origami and structured physical manipulation optimisation of fractions within the Nigerian classroom show a significant improvement in learners' interest and retention across the gender divide, thus closing historical gender gaps in basic mathematics performance (Obi, 2017).

Challenges, Structural Limitations, and Mitigation Strategies

While low-tech, high-impact (LTHI) instruments have numerous pedagogical advantages, there are certain challenges to incorporating them into the Nigerian educational system.

- Tight classrooms and teacher time poverty. Nigerian public-school teachers are often overworked with long hours of instruction, high grading responsibilities, and minimal remuneration. It's ludicrous to expect them to each make hundreds of manipulatives.
Mitigation: The Student Co-Creation Model is a mitigation approach. Teachers should turn tool creation into a practical activity under the National Curriculum's "Cultural and Creative Arts" (CCA) or "Basic Science and Technology" courses. Students collect their own bottle caps and cardboard to make tool-making an introductory lesson in spatial building and geometry.
- The Stigma of “Low-Tech” as “Inferior.” Some parents, teachers, and school administrators share a common psychological prejudice that physical, low-tech equipment manufactured from waste materials is outmoded or inferior to interactive whiteboards or digital tablets.

Mitigation: Advocacy based on evidence. Empirical research shows that the strategic use of homemade teaching materials with a collaborative learning approach leads to remarkable improvement in memory retention and self-motivation scores in science and technology courses (Imrana Garba Abdulkadir et al., 2025). School leaders should be shown local research data that shows that touching and handling tangible objects has more cognitive benefits than passively interacting with a screen.

- Infestation by Rodents and Storage. Cupboards and counters with food items (such as beans, groundnut shells, etc) are especially susceptible to pests and the humid weather typical of schools with open windows or doors.

Mitigation: Use only organic or paper items. You can use smooth river stones, broken plastic rulers, or plastic bottle tops in place of beans. A heavy-duty, upcycled 25-litre plastic oil jerrycan with an open side panel can provide a sealable, pest-proof storage chest for teachers.

Conclusion

You don't need high-tech to provide high-impact mathematics education. When low-tech instructional resources are deliberately designed around the ADCC framework, they provide a highly successful, climate-resilient, and socioeconomically equitable option for fostering deep conceptual mastery in resource-constrained contexts. Nigeria could close the educational equity gap by adopting low-tech, high-impact solutions to ensure its youth can succeed in STEM fields despite a lack of electricity or internet infrastructure. Nigerian mathematics education in the future would need to make inventive use of locally accessible resources in addition to digital innovation in an effort to provide equitable and significant learning opportunities for every student.

Suggestions

The following policy initiatives are recommended to effectively scale low-tech, high-impact (LTHI) mathematics tools across Nigeria:

1. The teacher's edition of national mathematics textbooks should be provided by the Nigerian Educational Research and Development Council (NERDC) with explicit guidance for low-tech virtual improvisation.
2. "Improvisation of Instructional Materials using Local Resources" should be made a core practical course by the National Teachers' Institute (NTI) and Faculties of Education in Nigerian institutions instead of a theoretical elective. Training for teachers needs to be constantly improved to increase their improvisational skills.
3. Public school clusters inside Local Government Areas (LGAs) should establish local "Math-Labs" for adjacent institutions to co-create, preserve, and swap enduring low-tech, high-impact (LTHI) instruments.
4. Utilise local resources and culturally relevant examples in your lessons.
5. Researchers need to empirically evaluate the utility of specific low-tech math tools in Nigerian classrooms.
6. Encourage teachers and students to work together to develop educational materials.
7. Professional development programs should focus on learner-centred mathematics instruction and improvisation.

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