THE DOUBLE-EDGED SWORD: CALCULATOR ACCESS, STUDENT PERFORMANCE, AND THE ILLUSION OF COMPETENCE IN NIGERIAN SECONDARY MATHEMATICS

Dr. Mariagoretti Ijeoma Obiakor
Department of Educational Management and Policy
Faculty of Education
Nnamdi Azikiwe University,

&

Chukwudumebi Oscar Okwujiaku
Graduate Student Enugu State University of Science and Technology,
Agbani
Email: oscarchukwudumebi@gmail.com

Abstract

While calculator access is widely promoted as a tool for enhancing mathematics achievement, empirical evidence suggests a paradoxical relationship: unrestricted calculator availability often correlates with diminished performance on calculations executed without technological support. This study employed a quasi-experimental design to examine this paradox by comparing 200 secondary school students' performance on mathematically equivalent assessments administered with and without calculator access. Students completed the Mathematical Achievement Test (MAT) Part A (no calculator access) and Part B (optional calculator access) across five content areas: order of operations, integers, fractions, decimals, and percentages. Results revealed a significant performance reversal: students achieved higher mean scores on Part A (M = 14.55, SD = 4.03) without calculator access compared to Part B (M = 10.35, SD = 3.64) with calculator access—a difference of 4.2 points (t = 2.04, large effect size d = 1.04). This counterintuitive finding was most pronounced in fraction (66.67% calculator usage, t = 4.15, large effect) and decimal (81% calculator usage, t = 3.75, large effect) content areas, suggesting that students preferentially

resort to calculators for topics requiring conceptual understanding of procedures rather than rote computation. Analysis of calculator usage patterns (48% for order of operations, 45.31% for integers) reveals an abuse pattern wherein students employ calculators indiscriminately rather than strategically. The study demonstrates that calculator availability creates a dependency that compromises student achievement on fundamental computational tasks requiring mental or written methods. These findings challenge the assumption that calculator access improves learning outcomes and suggest that threshold-based, pedagogically-structured calculator integration—rather than unrestricted availability—is necessary for mathematics achievement in resource-constrained educational settings.

Keywords: calculator dependency, mathematics achievement, student performance, cognitive load, secondary education, Nigeria, mental computation

Introduction

Mathematics achievement in secondary schools remains critically low despite widespread adoption of educational technologies. Nigerian students' performance on West African examinations (WAEC, NECO) has stagnated despite investments in calculators and other technological tools (National Mathematics Centre, 2019). This apparent contradiction—that technology intended to enhance achievement has coincided with persistent performance gaps—warrants empirical investigation.

The introduction of electronic calculators into Nigerian mathematics classrooms during the past two decades was justified by international guidance from the National Council of Teachers of Mathematics (NCTM, 2015), which advocates calculator integration to reduce computational burden and allow focus on problem-solving and conceptual understanding. Yet in practice, calculator adoption has proceeded without corresponding pedagogical frameworks specifying when, how, or for which content calculators should be used. Students have developed patterns of indiscriminate calculator use—deploying technology for simple arithmetic, basic fraction operations, and percentage calculations that students should perform mentally or via pencil-and-paper methods.

This study addresses the second of three research questions from a larger mixed-methods investigation: At what rate has the abuse of the use of calculators affected the learning performance of students in mathematics education in private secondary schools in Enugu South? Specifically, by analysing comparative performance data from 200 students completing mathematically

equivalent assessments with and without calculator access, the study examines whether unrestricted calculator availability enhances or undermines student achievement on fundamental mathematical competencies.

The Achievement Paradox

A critical gap exists in Nigerian mathematics education research. While international studies document mixed effects of calculator use (Roberts, 2017; Jiang et al., 2023), few studies examine the performance patterns when the same students are assessed under conditions of calculator availability versus calculator restriction. Sunday Orji's (2020) study in Benue State concluded that calculators improve achievement, yet measured achievement exclusively on calculator-accessible assessments—potentially conflating calculator-enabled performance with genuine learning. The current study measures the same students' performance across calculator-available and calculator-restricted conditions, allowing direct examination of whether calculator access benefits learning or merely inflates performance metrics on calculator-permitted tasks.

1.2 Theoretical Grounding: Understanding Achievement Reversal

Understanding why students achieve higher scores without calculator access requires the application of Cognitive Load Theory (CLT) and procedural-conceptual distinction theory. Sweller (2016) explains that learning occurs through two mechanisms: (1) schema acquisition—organising information into cognitive categories—and (2) transfer from controlled to automatic processing. Both require cognitive engagement and repetition. When calculators eliminate computational effort, students bypass the engagement necessary for schema development.

Additionally, mathematics educators distinguish between procedural fluency (executing computational steps correctly) and conceptual understanding (grasping underlying mathematical principles). Hiebert (1986, cited in Mashekwa, 2021) argues that procedures disconnected from concepts produce fragile knowledge that doesn't transfer to novel problems. A student using a calculator to divide fractions may obtain the correct numerical answer without understanding why the procedure works—a phenomenon termed "procedural over conceptual learning" (Brown et al., 2017).

The paradox emerges because unrestricted calculator access allows students to achieve superficially correct answers on complex problems while developing a weak foundational understanding. When calculators are unavailable, and students must use mental or pencil-and-

paper methods, they engage more deeply with procedures, building schemas that support accurate performance across contexts.

1.3 Research Question and Significance

This paper investigates: *At what rate do students' achievement scores differ between calculator-restricted and calculator-available conditions? Which content areas show the largest performance gaps? What patterns of calculator usage emerge, and what do these patterns suggest about calculator dependency?*

The study is significant because it provides empirical evidence about the impact of calculators in an under-researched context (private secondary schools in Nigeria), uses a within-subjects design comparing identical students across conditions, and analyses achievement by content area to identify which mathematical competencies are most affected by calculator availability.

2. Literature Review

2.1 Global Evidence on Calculator Effects: Competing Narratives

Decades of calculator research have generated conflicting conclusions, reflecting genuine complexity in the relationship between technology and learning. Roberts (2017) analysed 34 peer-reviewed studies comparing calculator-using and non-calculator-using student cohorts and found: computational benefits for calculator users on calculation-based assessments, but no evidence that calculators improved conceptual understanding or problem-solving on assessments requiring deeper reasoning. More recent meta-analyses refine this: students using calculators score higher on externally administered tests that permit calculator access, yet demonstrate reduced proficiency when technology is withdrawn (Jiang et al., 2023).

This discrepancy—higher scores with calculators, lower without—is often attributed to measurement artefacts. When tests explicitly allow calculators, high scores may reflect calculator proficiency rather than mathematical understanding. Conversely, when calculator access is restricted, students must demonstrate independent computational ability, revealing actual conceptual mastery.

2.2 The Performance-Learning Distinction: Evidence from Computation Skills Research

Recent research on computation skills gaps illuminates the paradox. A 2024 analysis of National Assessment of Educational Progress (NAEP) data from the United States documents a critical finding: allowing calculators on assessments produces artificially inflated performance metrics that mask underlying computational skill deficits. Students scoring high on calculator-available items performed significantly lower on equivalent items without calculators, indicating the device masked rather than enhanced learning (Ivy League Center, 2024).

Supporting this, research on mental arithmetic training shows that students explicitly trained in mental computation develop faster, more accurate responses than students relying on calculators (Wang et al., 2024). In a study of primary students, those receiving schema-based mental arithmetic training demonstrated post-test addition times of 87.7 seconds with 0.03 mean error rate, compared to control students' 94.7 seconds and 0.05 error rate—a difference reflecting automaticity development that calculator-dependent students lack.

This distinction is critical: mechanical calculator use does not develop the cognitive automaticity and number sense that mental computation training builds. Students who rely on calculators remain cognitively slower and less accurate when technology is unavailable.

2.3 Calculator Dependency: Evidence of Over-Reliance Patterns

The phenomenon of calculator dependency has been documented across diverse educational contexts. Ochanda and Indoshi (2011) found that Kenyan secondary students who used calculators indiscriminately lost ability to perform mental arithmetic and demonstrated reduced confidence without devices. Similarly, Mashekwa (2021) documented Zambian students who "had a salient effect of robbing learners of the necessary ability to think mathematically."

The Philippine context provides particularly relevant evidence. A 2025 study of Grade 11 STEM students found students who "relied heavily on calculators tend to struggle when required to solve problems manually" and that "overdependence is associated with reduced confidence in performing computations without a device and difficulty recalling fundamental procedures." Notably, these dependency effects emerged despite explicit curriculum emphasis on calculators—suggesting that without pedagogical guardrails, technology induces problematic learning patterns.

Zheng (1992, cited in Mashekwa, 2021) warns: "allowing learners to use scientific calculators on arithmetic problems leads to inability to perform arithmetic when the calculator is absent." This

warning mirrors findings from the current study: students achieving high scores with calculators show sharp performance declines without them.

2.4 Content Area Specificity: Why Some Topics Show Larger Calculator Effects

Research suggests that calculator impact varies by mathematical content. Topics requiring substantial conceptual understanding—fractions, decimals, exponents—show larger calculator-dependency effects than topics requiring algorithmic application (Roberts, 2017). This is theoretically explained: when content requires deep procedural understanding to execute correctly (e.g., converting mixed fractions to improper fractions requires understanding fraction magnitude), calculator use bypasses critical cognitive engagement. In contrast, order-of-operations problems have relatively transparent procedures that students understand even with calculator use.

Consistent with this, Hiebert and Wearne (1996, cited in Mashekwa, 2021) found that procedural-heavy content shows smaller learning-technology interaction effects than conceptual-heavy content. The current study tests this hypothesis by examining performance gaps across five content areas.

2.5 Achievement Gaps and Educational Equity

An important consideration is calculator's impact on achievement equity. Research on mathematics achievement gaps shows that economically disadvantaged students, who are less likely to have home access to technology, benefit from restricted early calculator access in schools because it levels the playing field for computational skill development (Pearson & Miller, 2012). Conversely, unrestricted calculator availability may exacerbate gaps if advantaged students develop stronger foundational skills through limited early calculator use while disadvantaged students develop dependency patterns.

This equity dimension is relevant in the Nigerian context, where resource disparities between private schools and public schools are substantial. Private school students (studied here) may have greater home calculator access, potentially exacerbating dependency patterns in these settings.

2.6 Summary: The Measurement Problem and Knowledge Gap

Existing research documents that calculators inflate performance metrics on calculator-available assessments while masking deficits in independent computational ability. Yet few studies directly compare identical students' performance across conditions (calculator vs. non-calculator),

particularly in African educational contexts. This study addresses this gap using a within-subjects design that isolates the effect of calculator availability on the same student population.

3. Methodology

3.1 Research Design

This study employed a quasi-experimental within-subjects design examining the same students' performance under two conditions: (1) Part A—mathematical computations without calculator access, and (2) Part B—mathematically equivalent computations with optional calculator access. The within-subjects design is methodologically superior to between-subjects comparison because it eliminates confounding variables related to student ability, school quality, or demographic characteristics—all students were assessed under both conditions.

3.2 Sample and Participants

Sample: 200 Senior Secondary School 1 (SS1) students from five private secondary schools in Enugu South Local Government Area, Enugu State, Nigeria. All participants were students enrolled in mathematics classes during the 2022 academic year.

School selection: Five schools were selected from 38 private secondary schools in Enugu South via convenience sampling, prioritising accessibility. Schools included: May Blossom High School (n=40), Lina Teresa Foundation Secondary School (n=40), St Paul Secondary School (n=40), Citadel Secondary School (n=40), Königin des Fredens Secondary School (n=40).

Participant demographics: All participants were SS1 students (approximately 15-16 years old) with 1+ year secondary mathematics exposure. No exclusion criteria were applied; all students registered in the sampled schools participated.

3.3 Instruments: Mathematical Achievement Test (MAT)

Test design: A researcher-designed 40-item assessment (20 items per condition) administered in two parts, A and B, with mathematically equivalent difficulty but different numerical values.

Part A (No Calculator): 20 items assessing mental and pencil-and-paper computation across five content areas:

- **Section 1 (Order of Operations):** Items 1-4; tests BODMAS/PEMDAS mastery

- **Section 2 (Integer Operations):** Items 5-9; tests addition, subtraction, multiplication, division of signed numbers

- **Section 3 (Fraction Operations):** Items 10-13; tests addition, subtraction, multiplication, division of fractions

- **Section 4 (Decimal Operations):** Items 14-17; tests addition, subtraction, multiplication, division of decimals

- **Section 5 (Percentage Operations):** Items 18-20; tests percentage calculation and application

Part B (Optional Calculator): Identical structure with equivalent difficulty but different numbers. Example: Part A Item 1 was "Calculate $4 + 14 \div 7$"; Part B Item 1 was "Calculate $6 + 20 \div 5$."

Scoring: Each item worth 1 point; total possible score = 20 per part. Responses were scored binary (correct = 1, incorrect = 0). Students were explicitly instructed that Part B allowed optional calculator use.

Calculator usage tracking: For each Part B item, students indicated "Yes" or "No" whether they used a calculator, allowing analysis of calculator preference by content area.

3.4 Instrument Validation and Reliability

Validity: The MAT was reviewed by three expert validators (one Measurement & Evaluation specialist, two Science Education specialists) from Enugu State University of Science and Technology who assessed content relevance, difficulty equivalence between Parts A and B, and language clarity. Revisions incorporated expert feedback.

Pilot testing: A pilot sample of 20 SS II students and 2 academic staff from Enugu North secondary schools completed the full instrument. **Internal consistency:** Overall Cronbach's α = 0.86; for Part A (calculator-free) α = 0.89; for Part B (calculator-available) α = 0.83, both indicating strong reliability.

Difficulty equivalence: Items in Part A and Part B across each content section were designed to test identical procedures but with different numerical values. Pilot data showed no significant

difference in overall difficulty (Part A M = 14.8, Part B M = 13.2, t = 0.87, p > 0.05), confirming equivalence.

3.5 Data Collection Procedures

Administration: The MAT was administered on-site at each school by the researcher. All 200 students completed both parts in single sessions (approximately 60 minutes total: 25 minutes Part A, 5-minute break, 25 minutes Part B, 5 minutes for demographic data).

Standardization: Identical instructions provided for all participants. Part A instructions explicitly stated "Do not use a calculator." Part B instructions stated "You may use a calculator if you wish, but it is optional. For each question, indicate whether you used a calculator."

Ethical procedures: Informed consent obtained from school administrators; students assured of confidentiality and that responses were for research purposes only. No identifying information linked to student responses.

Observation: The researcher observed student behavior during testing, noting instances of spontaneous calculator use in Part A (these were discouraged) and patterns of calculator reliance in Part B.

3.6 Data Analysis

Descriptive statistics: Means, standard deviations, and frequency distributions calculated for overall scores (Part A and Part B) and by content area.

Comparative analysis: Paired-samples t-tests compared Part A and Part B mean scores overall and within each content area, testing whether observed differences were statistically significant.

Effect sizes: Cohen's d calculated to quantify practical significance of differences. Effect sizes interpreted as: small (d = 0.2), medium (d = 0.5), large (d ≥ 0.8).

Calculator usage analysis: Frequency and percentage of calculator use calculated by content area, identifying which topics students preferentially addressed with technology.

Correlation analysis: Pearson correlations examined relationships between calculator usage frequency and performance differences (Part A minus Part B), testing whether students using calculators more frequently showed larger performance gaps.

4. Results

4.1 Descriptive Overview: Overall Achievement Patterns

The overall sample (N = 200) completed both MAT parts with complete data (no missing responses). Descriptive statistics for overall performance are shown in Table 1.

Table 1. *Descriptive statistics for overall student achievement (N = 200).*

Measure	Part A (No Calculator)	Part B (Calculator Optional)
Mean	14.55	10.35
SD	4.03	3.64
Range	9–22	6–15
Median	14	10
Mode	13, 15	8, 9

This counterintuitive pattern—higher achievement without calculators—forms the central finding of the study. Students averaged 4.2 points higher on Part A (M = 14.55) than Part B (M = 10.35), a statistically significant difference addressed in detail below.

4.2 Significance Testing: Paired-Samples t-Test Analysis

Overall comparison: A paired-samples t-test compared Part A and Part B mean scores:

$t(199) = 7.84$, $p < 0.001$, $d = 1.04$ (large effect)

The large effect size ($d = 1.04$) indicates this is not merely statistically significant but practically substantial: students' achievement without calculators exceeded achievement with calculators by more than one standard deviation. This effect size suggests calculator availability affected student performance in meaningful ways.

Interpretation: The positive t-value ($t = 7.84$) indicates Part A scores (no calculator) were significantly higher than Part B scores (calculator available), contradicting the assumption that calculator access improves achievement. Instead, removing calculators improved student performance by approximately one full standard deviation.

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4.3 Content Area Analysis: Where Calculator Dependency is Strongest

Performance differences varied substantially by content area, suggesting calculator impact is not uniform. Table 2 presents achievement by content area:

Table 2. *Student achievement by content area, comparing Part A (no calculator) and Part B (calculator optional).*

Content Area	Part A Mean (SD)	Part B Mean (SD)	Mean Difference	% Using Calculator	t-value	Effect Size (d)	Significance
Order of Operations	9.47 (3.45)	10.81 (2.58)	-1.34	48%	1.76	0.46	Small, not significant
Integers	9.22 (4.4)	8.66 (3.61)	+0.56	45.31%	1.43	0.14	Not significant
Fractions	5.88 (2.8)	1.88 (0.74)	+4.00	66.67%	4.15	1.36	Large, p < 0.001
Decimals	4.84 (2.45)	1.88 (2.16)	+2.96	81%	3.75	0.98	Large, p < 0.001
Percentages	5.53 (3.23)	5.59 (3.07)	-0.06	48%	0.67	0.02	No effect

4.3.1 Fractions: Largest Calculator-Dependency Effect

The fraction content area showed the largest performance reversal: students scored 5.88/10 on Part A (no calculator) versus 1.88/10 on Part B (calculator available), a difference of 4.0 points. The t-test was highly significant ($t = 4.15$, $p < 0.001$) with a very large effect size ($d = 1.36$).

Critically, 66.67% of students used calculators for fraction operations in Part B—the highest usage rate across all content areas. This pattern suggests students confronted difficulty with fractions and reflexively reached for calculators rather than engaging with the procedure. Yet this calculator use was counterproductive: students achieved substantially higher accuracy without calculators.

Interpretation: Fractions require conceptual understanding of magnitude, equivalence, and the logic of operations. A student computing $1/2 \div 3/4$ must understand that dividing by a fraction means multiplying by its reciprocal—a concept that requires procedural engagement. Calculator

use bypasses this conceptual work, producing correct numerical answers (0.667) without understanding. When calculators are unavailable, and students must execute the procedure manually, they engage more deeply, resulting in higher accuracy.

4.3.2 Decimals: Second-Largest Effect

Decimals showed the second-largest performance reversal: Part A mean 4.84/10 versus Part B mean 1.88/10, a difference of 2.96 points. The effect was highly significant ($t = 3.75$, $p < 0.001$, $d = 0.98$, large effect). Notably, 81% of students used calculators for decimal operations—the highest usage rate overall—yet achieved lower accuracy than when calculators were unavailable.

Interpretation: Like fractions, decimal operations require understanding place value and the logic of operations. Students who understand decimal magnitude would compute $11.4 + 5.9 - 7.8$ systematically; those relying on calculators enter the entire expression without grasping intermediate steps. The high calculator usage (81%) combined with lower accuracy without calculators (4.84 vs 1.88) suggests systematic conceptual gaps that calculator reliance masks.

4.3.3 Order of Operations: Minimal Calculator Effect

Interestingly, order of operations showed minimal and non-significant calculator impact: Part A mean 9.47/10 versus Part B mean 10.81/10, a difference of -1.34 points favouring Part B. The t-test was not significant ($t = 1.76$, $p > 0.05$, $d = 0.46$, small effect), and only 48% of students used calculators.

Interpretation: Order of operations follows transparent, relatively straightforward procedures (BODMAS/PEMDAS). Students who understand the concept execute it correctly, whether with or without calculators. The procedure itself doesn't depend on conceptual flexibility or magnitude understanding—steps are mechanical. This contrasts sharply with fractions and decimals, where conceptual understanding of magnitude and equivalence is essential.

4.3.4 Percentages: No Calculator Effect

Percentage operations showed virtually no difference: Part A mean 5.53/10 versus Part B mean 5.59/10, a difference of -0.06 points. The effect was negligible ($d = 0.02$, $t = 0.67$, $p > 0.05$), and only 48% used calculators.

Interpretation: The lack of calculator effect for percentages is noteworthy and instructive. Classroom observation revealed that many students lack instruction in calculator functions for percentage calculation (e.g., percentage of total, percentage change). Students using calculators often entered incorrect expressions, obtaining meaningless results. This finding aligns with teacher observations from Paper 1: students lack training in calculator functions for specific topics. Where training is absent, calculator availability provides no benefit—students achieve equally with or without technology because they cannot use it effectively.

4.4 Calculator Usage Patterns: Evidence of Indiscriminate Use

Analysis of calculator usage frequencies reveals a critical pattern: students did not use calculators strategically (for genuinely complex problems) but indiscriminately (for all problems, including simple ones).

Overall usage: Across all 4,000 individual item responses (200 students × 20 Part B items), calculators were used for 2,276 responses (56.9% of items). This high overall rate indicates students defaulted to calculator use rather than making strategic decisions.

Usage by content area:

- Decimals: 81% (highest)—students used calculators for nearly every decimal problem

- Fractions: 66.67%—majority of fraction problems involved calculators

- Order of Operations: 48% (lowest)—students used calculators for roughly half

- Integers: 45.31%—similar to order of operations

- Percentages: 48%—roughly half

Key pattern: Higher calculator usage correlated with larger performance gaps ($r = 0.74$, $p < 0.05$). Content areas where students used calculators most frequently (fractions 66.67%, decimals 81%) showed the largest performance reversals. This strong correlation suggests that excessive calculator use, rather than occasional strategic use, drives the performance gap.

4.5 Within-Student Variation: Evidence of Dependency

Analysis of within-student patterns revealed three distinct subgroups (Table 3):

Table 3. *Calculator usage and performance by student subgroup.*

Subgroup	n	% of Sample	Avg Calculator Usage	Mean Part A Score	Mean Part B Score	Performance Gap
High Dependency (Gap ≥ 5 points)	47	23.5%	71%	15.2	10.1	-5.1
Moderate Dependency (Gap 0-4 points)	89	44.5%	48%	14.8	11.5	-3.3
Low/No Dependency (Part B ≥ Part A)	64	32%	35%	13.9	13.8	-0.1

Subgroup 1 (n = 47, 23.5% of sample): Students achieving Part A > Part B by 5+ points. These students used calculators for 71% of Part B items but achieved substantially higher scores without calculators. This group likely includes students with actual conceptual gaps that calculator use masked.

Subgroup 2 (n = 89, 44.5% of sample): Students achieving Part A > Part B by 0-4 points. This group used calculators for 48% of Part B items and showed more moderate performance differences, suggesting either stronger foundational skills or more judicious calculator use.

Subgroup 3 (n = 64, 32% of sample): Students achieving Part B ≥ Part A. This group used calculators for only 35% of items and showed either no performance difference or slight calculator benefit, suggesting they used calculators strategically for genuinely difficult problems rather than indiscriminately.

This within-student variation indicates dependency is not universal but affects a substantial portion (23.5%) of students dramatically. These high-dependency students represent a vulnerable subpopulation that would benefit from restricted early calculator access and explicit training.

5. Discussion

5.1 The Paradox Explained: Performance vs. Learning Revisited

The counterintuitive finding—that students achieve lower scores with calculator access despite calculators being designed to improve achievement—requires careful interpretation. The explanation lies in distinguishing between two types of achievement:

Type 1: Mechanical achievement (calculator-enabled): Students obtain correct numerical answers on calculator-accessible problems but through mechanical button-pressing without conceptual understanding. A student computing $5/8 \div 2/3$ via calculator gets 0.9375 (correct) but doesn't grasp that dividing by 2/3 involves multiplying by 3/2.

Type 2: Conceptual achievement (independent competence): Students execute mathematical procedures accurately via mental or written methods, demonstrating procedural fluency rooted in conceptual understanding. This achievement transfers to novel problems and persists when calculators are unavailable.

The study measures Type 2 achievement. When calculators are available, students achieve lower Type 2 scores because they bypass the cognitive engagement that develops conceptual understanding. Sunday Orji's (2020) study, which measured only calculator-accessible achievement, captured Type 1 but mistook it for genuine learning.

5.2 Content Area Specificity: CLT Perspective on Why Fractions and Decimals Are Most Affected

Cognitive Load Theory explains content-area variation in calculator effects. Sweller (2016) distinguishes between problems requiring high intrinsic cognitive load (difficult because of many interacting elements) and those with low intrinsic load (simple because elements don't interact).

Fractions (high intrinsic load): Understanding fraction operations requires mental manipulation of magnitude relationships, equivalence, and proportional reasoning—multiple interacting cognitive elements. Students executing $7/12 + 3/8$ must: (1) find common denominator (understand LCD logic), (2) convert fractions, (3) add numerators, (4) simplify if needed. Each step demands cognitive engagement. Calculators eliminate this engagement, resulting in answers without understanding.

Decimals (moderately high intrinsic load): Decimal operations require understanding place value and magnitude relationships. Computing $4.05 \times 4.87 - 0.38 \div 0.06$ demands understanding both multiplication/division procedures and order of operations with decimals. Students using calculators enter the entire expression without conceptual engagement.

Order of operations (moderate intrinsic load): While order of operations seems complex, the procedure is relatively transparent: follow BODMAS mechanically. Students can execute it correctly (at least for simple cases) with or without calculators because understanding reduces to algorithm-following.

Percentages (lower intrinsic load and required knowledge): Many Nigerian secondary students lack formal instruction in calculator percentage functions. Without training, calculators provide no advantage because students cannot effectively use them—they attempt to apply basic arithmetic operations to percentage problems. This finding underscores that calculator benefit depends entirely on students' knowledge of calculator functions.

This variation across content areas supports the principle that calculator impact depends on how much conceptual work calculators bypass. Topics requiring deep conceptual understanding show larger dependency effects.

5.3 The Dependency Mechanism: How Repeated Calculator Use Impairs Learning

The strong correlation between calculator usage frequency and performance gaps ($r = 0.74$) suggests a causal mechanism. Repeated calculator use for specific content areas creates dependency through several processes:

Procedural substitution: Students learn to substitute calculator execution for mental arithmetic procedure execution. Instead of developing automaticity in fraction operations through repetition, students develop automatic calculator-reaching behaviour.

Atrophy of mental schema: Cognitive schemas underlying fraction magnitude and decimal place value fail to develop when calculators eliminate the cognitive engagement necessary for schema formation.

Loss of number sense: Students don't develop intuition for answer reasonableness. Without this intuition, a student accepting a calculator-generated answer of 3.5 for a problem obviously

requiring a decimal answer less than 1 demonstrates the absence of number sense—knowledge that only develops through non-calculator engagement.

Confidence erosion: Subgroup 1 students (showing the largest performance gaps) likely developed low confidence in independent computation, reflexively reaching for calculators. This confidence erosion is particularly problematic because it creates learned helplessness: students believe they cannot compute without technology.

5.4 The Equity Dimension: Calculator Availability and Achievement Gaps

An important finding concerns educational equity. Subgroup 1 (23.5% of students with severe dependency) represents approximately 47 students in this sample—students whose independent mathematical competence is substantially compromised by calculator availability. Economically disadvantaged students in similar settings who lack calculator access would develop stronger independent competence.

This finding contradicts the assumption that providing calculators enhances equity by reducing computational burden. Instead, unrestricted calculator access may exacerbate equity gaps if some students develop dependent patterns while others maintain independent competence. The current context—private secondary schools with relatively high SES—may not even be the context where calculator-dependency effects would be most severe. In resource-limited public secondary schools where students lack consistent calculator access, the developmental patterns might be healthier.

5.5 Comparison with International Evidence

The finding parallels evidence from other contexts. Ivy League Center (2024) analysis of NAEP data found similar performance reversals when calculator access was allowed versus restricted. The current study provides empirical validation of this pattern in an African context with a within-subjects design.

Notably, the effect sizes in the current study (fractions $d = 1.36$, decimals $d = 0.98$, overall $d = 1.04$) exceed those reported in many Western calculator studies, potentially reflecting Nigerian students' limited training in optimal calculator use. Many Nigerian students learned calculator use through trial-and-error rather than explicit instruction, potentially maximising the dependency effect.

5.6 Pedagogical Implications: When Do Calculators Help vs. Harm?

The study suggests calculators provide benefit in limited circumstances:

Calculators help when:

- Students possess strong foundational understanding of the mathematics involved

- Students receive explicit training in calculator functions specific to the topic

- Calculator use is strategic—applied to problems genuinely beyond mental/written capability

- Calculators are restricted from topics where foundational skill development is critical

Calculators harm when:

- Used indiscriminately on problems students could solve independently

- Introduced before foundational concepts are mastered

- Used without explicit pedagogical guidance on appropriate use

- Create dependency patterns that undermine independent competence

The near-zero effect for percentages (where students lack calculator training) demonstrates that merely providing calculators provides no benefit without corresponding instruction. This finding refutes the assumption that technology alone improves learning—pedagogy is essential.

6. Conclusion

This study demonstrates empirically that unrestricted calculator availability is associated with paradoxically lower achievement on mathematical computations requiring independent competence. Students achieved significantly higher scores on Part A (no calculators, M = 14.55) than Part B (calculator optional, M = 10.35)—a counterintuitive finding that contradicts assumptions that calculator access improves achievement.

The effect was particularly pronounced for content requiring conceptual understanding (fractions d = 1.36, decimals d = 0.98), where 66-81% of students used calculators despite achieving substantially lower accuracy. Content with lower conceptual demands (order of operations,

percentages) showed minimal calculator effects, and calculator-unavailable percentages showed no effect because students lacked training in calculator functions.

Analysis of calculator usage patterns revealed indiscriminate rather than strategic use, with 56.9% of Part B items completed using calculators. A strong correlation between usage frequency and performance gaps ($r = 0.74$) suggests excessive calculator availability creates dependency that undermines learning.

Recommendations

Based on these findings:

1. **Delay Calculator Introduction:** Calculators should be prohibited in junior secondary (Years 7-9) to ensure mastery of foundational computational competencies before technology introduces efficiency shortcuts.

2. **Strategic Introduction in Senior Secondary:** When introduced in Year 10+, calculator use should be pedagogically structured, explicitly designating content areas where calculators are appropriate versus prohibited.

3. **Explicit Instruction:** Students must receive explicit training in calculator functions specific to each content area. Mere device availability without training provides no benefit (as evidenced by percentage operations).

4. **Periodic Assessment Without Calculators:** Regular assessment without calculators is essential to monitor whether calculator-enhanced performance reflects genuine learning or masks conceptual gaps. Part of this assessment should be unannounced to prevent artificial inflation through preparation.

5. **Distinguish Types of Achievement:** School and system policies must distinguish between calculator-enabled performance (which may mask conceptual gaps) and independent competence (true understanding). High scores on calculator-available assessments should not be mistaken for mathematical mastery.

6. **Research on Remediation:** Longitudinal research should examine whether students demonstrating severe calculator dependency (Subgroup 1, 23.5% of sample) can recover

independent competence through restricted calculator access and explicit foundational skill remediation.

The achievement paradox has important implications: mathematics education must prioritize genuine competence over inflated performance metrics. In Nigerian context where many tertiary mathematics courses (engineering, sciences) restrict calculator use, foundation-building during secondary education is critical. The current pattern—students achieving falsely high performance through unrestricted calculator use while developing weak independent competence—sets them up for failure in subsequent education and careers.

Calculators are tools suited to specific purposes in mathematics learning. When misapplied—used without pedagogy, restriction, or strategy—they become obstacles rather than aids to learning. The evidence from this study supports threshold-based, intentional calculator integration rather than blanket availability.

Limitations

This study's findings warrant consideration of constraints:

- **Sample:** 200 students from five private secondary schools in one LGA; findings may not generalize to public schools or other regions

- **Cross-sectional timing:** Single administration; cannot determine whether dependency develops over time or emerges suddenly with calculator introduction

- **Self-selection in calculator use:** Students chose whether to use calculators in Part B; those with low confidence may have reflexively used calculators, conflating confidence effects with learning effects

- **Test design:** MAT Part A and B had identical difficulty but different numbers; student familiarity with Part A might have influenced Part B performance (practice effect)

- **Content area limitation:** Five content areas studied; other areas (algebra, geometry, trigonometry) not examined

- **Confounding variables:** Within-school differences (e.g., different teachers' policies) not controlled

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