



RESEARCH ARTICLE

Effects of Braille Mathematical Code Instruction and Concrete Materials on Mathematics Performance in Primary School Learners with Total Blindness: A Quasi-Experimental Study in Oyo State, Nigeria

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Abstract: Mathematics learning for learners with total blindness is constrained by limited access to symbolic and tactile representations. This study examined whether Braille Mathematical Code (BMC) instruction and Concrete Materials (CM) improve mathematics performance among primary-school learners with total blindness in Oyo State, Nigeria, and assessed gender and academic self-efficacy effects. Using a pretest–posttest control-group quasi-experimental design with three treatment conditions (BMC, CM, and conventional instruction), 45 learners with total blindness completed a six-week program (1-week pretest, 4-week intervention, 1-week posttest). Screening and measurement used a Teacher Observation Report, Snellen Chart, an Academic Self-Efficacy Scale, and a Braille-accessible Mathematics Performance Assessment. Posttest performance was analyzed with ANCOVA controlling for pretest scores, followed by Bonferroni-adjusted pairwise comparisons; gender differences were examined with an independent-samples t test, and self-efficacy categories with one-way ANOVA. ANCOVA showed a significant main effect of treatment on posttest performance, $F(1,35)=12.46$, $p=.001$, $\eta^2=.263$, although Bonferroni pairwise contrasts were non-significant. Gender was not significant ($t(43)=0.709$, $p=.484$). Academic self-efficacy differed significantly across categories, $F(2,42)=7.89$, $p=.001$. Accessible instructional supports are associated with improved mathematics outcomes for learners with total blindness, and self-efficacy is a relevant learner factor. Future work should strengthen cluster-aware designs and fidelity reporting in schools.

Keywords: Braille Mathematical Code; concrete materials; mathematics performance; total blindness; academic self-efficacy; quasi-experimental design; inclusive mathematics education; tactile learning.

INTRODUCTION

Globally, visual impairment and blindness remain highly prevalent and carry substantial educational and economic consequences, particularly in low-resource settings where access to inclusive services and learning materials is uneven (World Health Organization [WHO], 2026). In such contexts, strengthening equitable access to foundational competencies—especially mathematics—is not only a disability-rights imperative but also an instructional priority because mathematics is a gateway domain for later STEM participation, problem solving, and school-to-work transitions. Yet, international evidence consistently shows that many education systems still struggle to deliver “inclusion that works” for learners with disabilities due to gaps in teacher preparation, assistive resources, and

accessible curricula (UNESCO, 2020). In Sub-Saharan Africa specifically, empirical work highlights that inclusive education for learners with visual impairment is constrained by limited specialist support, shortages of accessible materials, and variability in classroom implementation—conditions that can directly suppress learning outcomes in content areas that rely heavily on symbol systems and representations such as mathematics (Le Fanu et al., 2022).

Mathematics presents distinctive access barriers for learners with total blindness because core ideas are frequently communicated through visual structures—spatial layouts, graphs, diagrams, place-value alignment, and symbolic notation. When these representations are unavailable or poorly adapted, learners may experience reduced opportunities to build conceptual understanding and procedural fluency, and teachers may default to verbal explanations that do not fully substitute for structured, manipulable representations. For learners who rely on tactile channels, accessibility requires deliberate instructional design that converts visual information into systematic tactile forms (e.g., tactile graphics, raised-line diagrams, consistent symbol sets) and ensures that these materials are teachable, readable, and assessable in

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classroom conditions (Producers of Accessible Graphics, 2010). In parallel, advances in assistive technology and accessible math authoring have expanded the toolkit for producing and delivering mathematics content in non-visual formats; however, these solutions still depend on teacher knowledge and local feasibility (Shoaib et al., 2023).

One foundational pathway to equitable mathematics access is mastery of a standardized braille mathematical code—a rule-governed system for representing mathematical symbols, spatial arrangements, and multi-line expressions in braille. In many contexts, this functionality is provided through established codes such as the Nemeth Braille Code for Mathematics and Science Notation, which specifies conventions that support accurate reading/writing of mathematical expressions and reduce ambiguity when translating between print and braille (Braille Authority of North America, 2022a). However, the instructional effectiveness of braille math code use is not automatic: it requires explicit instruction, consistent transcription, and teacher competence. Professional development evidence underscores that competence in teaching and applying braille math code (including Nemeth within Unified English Braille contexts) varies across personnel and can be strengthened through targeted training, with potential downstream benefits for students' mathematics learning opportunities (Herzberg et al., 2024). In practical terms, braille math code instruction can improve students' access to symbolic precision—supporting computation, expression manipulation, and alignment with formal mathematics language—provided that instruction is systematic and paired with meaningful problem contexts.

A complementary access pathway is the strategic use of concrete materials (hands-on manipulatives) adapted for tactile learning. Concrete materials can externalize abstract concepts—quantity, equivalence, place value, measurement, and basic geometry—through structured tactile interaction. Meta-analytic evidence in general education indicates that teaching mathematics with concrete manipulatives yields statistically significant learning benefits compared with instruction using only abstract symbols, with effects varying by instructional conditions and outcome types (Carbonneau et al., 2013). For learners with total blindness, the conceptual case for concrete materials is especially strong because tactile interaction can serve as an “access bridge” to mental models that sighted learners often build through visual observation. Nevertheless, concrete materials must be instructionally integrated rather than treated as add-ons; without clear mappings from tactile actions to mathematical structures and symbols, manipulatives may increase confusion or fragment learning.

Theoretical grounding helps clarify why braille math code and concrete materials may influence mathematics outcomes and under what conditions those effects may differ. From a cognitive load perspective, instruction is more likely to succeed when it reduces unnecessary (extraneous) load and supports learning-relevant (germane) processing—especially for learners who must coordinate tactile exploration, working memory, and symbolic decoding. Cognitive load theory further emphasizes that instructional effectiveness depends on learner characteristics and task demands, implying that accessibility interventions should be evaluated not only for main effects but also for differential benefits across learners (Sweller, 2024). From a social cognitive perspective, learners' beliefs about their capability—particularly academic self-efficacy—shape persistence, strategy use, and willingness to engage with challenging tasks. A robust synthesis literature shows that academic self-efficacy is meaningfully associated with

academic performance and can operate as a mechanism that strengthens or weakens the impact of instruction (Honicke & Broadbent, 2016). These two lenses jointly suggest a plausible model: braille math code and concrete materials may improve mathematics performance by improving representational access and instructional efficiency, while students' self-efficacy may condition how effectively they capitalize on these opportunities.

Accordingly, it is theoretically defensible to test whether treatment effects differ by gender and academic self-efficacy. Cross-national meta-analytic evidence indicates that gender differences in mathematics are generally small and highly context-dependent, shaped by cultural, instructional, and opportunity structures (Else-Quest et al., 2010). In addition, experimental meta-analysis demonstrates that situational factors—such as stereotype-based cues—can affect performance outcomes, implying that psychosocial context may interact with instructional conditions (Nguyen & Ryan, 2008). In settings where learners with disabilities face compounded barriers (resource constraints, low expectations, limited specialist support), these moderating dynamics may be particularly salient. Therefore, positioning gender and academic self-efficacy as moderators is not merely a statistical choice; it aligns with theory about differential responsiveness to instructional supports under varying motivational and social conditions.

Despite the conceptual promise of braille math code instruction and tactile-concrete approaches, an important empirical gap remains: there is limited context-specific experimental or quasi-experimental evidence that directly compares these two instructional strategies for primary-school learners with total blindness in Oyo State, Nigeria, while also testing whether effects vary by gender and academic self-efficacy. This gap matters because intervention feasibility and effectiveness are strongly shaped by local realities—availability of braille transcribers, teacher expertise, access to manipulatives, and school-level support for inclusive practice. Evidence from the Sub-Saharan African region indicates that implementation constraints can dilute otherwise sound inclusive interventions, underscoring the need for locally grounded effectiveness studies (Le Fanu et al., 2022).

In this study, mathematics performance is operationalized as students' achievement on a curriculum-aligned, braille-accessible Mathematics Performance Assessment administered as a pretest and posttest. The assessment is intended to capture grade-appropriate competencies emphasized in primary mathematics (e.g., number and operations, basic measurement/geometry concepts, and word-problem reasoning), with total scores reflecting accuracy on the performance tasks. The study evaluates whether instruction using Braille Mathematical Code (BMC) and instruction using Concrete Materials (CM) differentially influence post-intervention mathematics performance, while examining gender and academic self-efficacy as moderators of these effects (and, where relevant for internal validity, treating background factors such as parental socioeconomic resources as covariates rather than competing moderators to maintain a single coherent model).

Statement of the Problem

Even with great improvements in teaching aids and materials, teaching mathematics to students with visual impairments still presents substantial obstacles. Mathematics is a foundational subject that plays a crucial role in academic success and everyday life. However,

learners with total blindness face significant challenges in mathematics education due to the inherent reliance on visual representations and traditional teaching methods that do not accommodate their needs. These challenges can lead to lower academic performance and limited opportunities for these learners in educational settings and beyond. Despite advancements in assistive technologies and teaching strategies, there remains a gap in effective instructional approaches that specifically address the unique learning requirements of students with total blindness in mathematics. Traditional methods, which often rely on visual aids, do not adequately support these learners, resulting in difficulties in understanding mathematical concepts, problem-solving, and applying mathematics in real-world contexts.

Furthermore, the impact of gender and academic self-efficacy as moderating variables in the educational outcomes of learners with total blindness has not been thoroughly explored. Gender disparities in mathematics performance persist in many educational settings, and it is essential to understand how these disparities manifest in learners with disabilities. Additionally, academic self-efficacy, or the belief in one's ability to succeed in specific tasks, plays a significant role in academic performance, yet its influence in the context of visually impaired learners remains under-researched.

Thus, the problem addressed by this study is the need to investigate the effectiveness of Braille mathematical code and concrete materials as instructional strategies for enhancing the mathematics performance of learners with total blindness.

Additionally, it is essential to explore how gender and academic self-efficacy moderate the relationship between these teaching methods and mathematics performance. Without a deeper understanding of these processes, educators may find it difficult to provide effective support to students who are completely blind, perpetuating educational inequities and limiting their educational opportunities.

This study aims to fill existing research gaps by examining how Braille mathematical code and concrete materials can improve mathematics performance among blind students, and balancing gender roles and reassessing academic ability. These findings are valuable knowledge to improve teaching practices and promote equal mathematics education for all learners, regardless of visual impairment.

Purposes of the Study

The purpose of this study is to investigate the effect of Braille mathematical code and the use of concrete materials on the mathematics performance of learners who are totally blind of primary school in oyo state, Nigeria. The purpose of this study is to find out how these tools contribute to increasing the understanding and application of mathematical concepts among visually impaired learners.

Additionally, this study examines how the relationship between these teaching methods and mathematics achievement is moderated by gender and academic ability. Concrete content is related to the student's gender and his/her belief in academic ability (self-efficacy).

By examining these variables, this study aims to consider the most effective teaching strategies to improve mathematics learning for all blind students, paying particular attention to the impact of conditions Individuals such as gender and self-efficacy affect learning outcomes. Specific objective of the study include;

1. To assess how the use of Braille mathematical code and concrete materials influence the mathematics performance of learners with total blindness.
2. To analyze whether gender moderates the relationship between the use of Braille mathematical code and concrete materials and mathematics performance.
3. To explore how academic self-efficacy influences the effectiveness of Braille mathematical code and concrete materials on the mathematics performance of learners with total blindness.

Hypothesis

Hypothesis (H₀₁)

There is no significant main effect of treatment on performance in mathematics among learners with total blindness in Oyo state.

Hypothesis (H₀₂)

There is no significant main effect of gender in improving performance in mathematic samong participants.

Hypothesis (H₀₃)

There is no significant main effect of academic self-efficacy in improving performance in mathematics among learners with total blindness.

METHODS

Research design

This study employed a pretest–posttest control group quasi-experimental design structured within a $3 \times 2 \times 3$ factorial matrix, to examine the effects of two instructional interventions–Braille Mathematical Code (BMC) and Concrete Materials (CM)–on mathematics performance among learners with total blindness. The design incorporated three treatment conditions (BMC, CM, and conventional instruction/control), crossed with gender (male/female) and academic self-efficacy (high/moderate/low) as moderating factors. This approach was selected because it enables a rigorous comparison of post-intervention performance while accounting for baseline differences via pretest scores as a covariate and exploring whether intervention effects vary systematically by learner characteristics.

The research was conducted in selected public primary schools located in Oyo State, Nigeria. The schools were chosen based on the presence of specialized services for learners with visual impairment, the feasibility of implementing the planned interventions, and the availability of an environment supportive of structured instruction. The broader context underlying this choice is that mathematics instruction often relies heavily on visual representations, creating persistent accessibility barriers for learners with total blindness–hence the need to test tactile and Braille-based alternatives in authentic school settings.

Population and Participants

The target population comprised pupils with total blindness enrolled in selected public primary schools in Oyo State. "Total blindness" in this study refers to learners who are unable to rely on functional vision for accessing classroom instruction and who therefore require tactile and/or auditory modalities for reading, writing, and

engaging with mathematical representations. The study's screening procedure (detailed below) was designed to ensure that included participants met the operational criteria for total blindness.

From the results section reported in the manuscript, the total sample involved 45 learners, distributed across the three treatment conditions as follows: Concrete Materials ($n = 20$), Braille Mathematical Code ($n = 16$), and Control ($n = 9$). While the manuscript also reports gender counts in a separate analysis (male and female groups), the critical point for this methodology narrative is that participants spanned both genders and varied across academic self-efficacy levels, enabling moderation analyses aligned with the factorial structure.

Sampling Procedure

A multi-stage sampling procedure was used. Stage I (Selection of Local Government Areas). The study began with purposive selection of three Local Government Areas within Oyo State. This step was intended to ensure that selected areas contained schools serving learners with total blindness and could support the implementation timeline. Stage II (Selection of Schools). Next, one public primary school was selected from each of the three chosen Local Government Areas using simple random sampling. The selected schools were described as having specialized services, appropriate localization and socio-amenities, and a conducive learning environment.

Stage III (Selection of Participants and Assignment to Conditions). In the final stage, purposive sampling was applied to identify and recruit learners with total blindness from each selected school. Learners were screened using standardized procedures and instruments to confirm eligibility. Importantly, the quasi-experimental nature of the study is reflected in how the intervention conditions were implemented at the school level: one school received the Braille Mathematical Code intervention, one school received the Concrete Materials intervention, and the third school served as the control group. This school-level allocation reduces contamination risk (e.g., learners in the same school being exposed to both interventions) but also means that random individual assignment was not the primary allocation mechanism, consistent with quasi-experimental design.

Eligibility Criteria

Participants were included if they: (a) were pupils with total blindness enrolled in the selected public primary schools, (b) scored low on the mathematics pretest (supporting a focus on learners needing improvement), and (c) indicated willingness to participate. These criteria align the sample with the study's intent to evaluate whether BMC and CM can improve mathematics performance among learners facing pronounced access barriers and learning challenges.

Interventions

Braille Mathematical Code (BMC) Condition.

Learners in this group received mathematics instruction emphasizing the use of Braille mathematical notation (referred to in the manuscript as Braille mathematical code, often aligned in practice with structured systems such as Nemeth-based notation). The instructional intent was to provide a systematic tactile representation of mathematical symbols, operations, and expressions so learners could read and write mathematics independently and accurately. The

intervention was described as a targeted instructional approach delivered during the treatment period.

Concrete Materials (CM) Condition.

Learners in this group received mathematics instruction supported by concrete/tactile materials (manipulatives). These resources are intended to make abstract concepts tangible through hands-on exploration—particularly valuable for number sense, operations, geometry, and spatial reasoning tasks that are typically taught visually. The manuscript frames concrete materials as tactile resources enabling active manipulation and kinesthetic reinforcement of mathematical concepts.

Control (Conventional Instruction) Condition.

Learners in the control group received regular, conventional teaching without additional structured exposure to BMC-focused methods or enhanced concrete/tactile supports beyond what might normally be used.

Measures and Research Instruments

The following instruments were used in the study viz Teacher Observation Report, Snellen Chart, Academic Self-efficacy scale and Mathematics Performance Assessment Test.

Teacher Observation Report

The Teacher Observation Report serves as a qualitative tool utilized to collect data regarding the visual impairment conditions of the learners, particularly distinguishing those who experience total blindness. This report holds significant importance because classroom teachers are knowledgeable about the learners and can offer comprehensive insights into their visual capabilities derived from ongoing interactions and observations.

The report from the teacher aids in affirming the inclusion of learners with total blindness as subjects in the research. By utilizing the teacher's expertise, the researcher guarantees the correct identification of the target population, which is vital for the study's validity and reliability.

The researcher works in conjunction with the classroom teacher to acquire a written document that specifies the visual impairment status of each learner. This report aims at pinpointing learners who are completely blind, based on the teacher's extensive observation and comprehension of the learner's strengths and difficulties in navigating the classroom setting and educational materials.

Snellen Chart

The Snellen chart serves as a commonly utilized instrument to gauge visual acuity. For this study, it may be employed to verify the complete blindness status of the participants. Although it does not directly evaluate mathematics performance, utilizing the Snellen chart guarantees that the research accurately targets learners with total blindness, confirming their eligibility for participation in the study.

Academic Self-Efficacy Scale

The academic self-efficacy scale is a self-develop scale designed to gauge learners' confidence in their capability to succeed in academic activities, including mathematics. For learners who are totally blind, this scale could be modified to evaluate their confidence in mastering mathematical concepts using Braille codes and concrete materials. Self-efficacy is essential for academic achievement. This tool assesses how the interventions influence learners'

confidence in their mathematical skills, providing valuable insights into the psychological components of performance.

Mathematics Performance Assessment Test

This assessment aims to objectively evaluate the mathematics abilities and knowledge of learners with total blindness prior to and following the interventions. It is organized to feature items that evaluate essential mathematical principles while taking into consideration the learners' utilization of Braille Mathematical Code and tactile materials. The main objective of the research is to evaluate the effect of Braille Mathematical Code and tactile materials on mathematical performance. This tool directly assesses the outcome variable (mathematics performance), making it crucial to the study.

Procedure for Data Collection

Data collection followed a clearly defined sequence over six (6) weeks, comprising: one week of pretest, four weeks of targeted treatment, and one week of posttest. Prior to field implementation, the researcher obtained formal permission from the Department of Special Education at University of Ibadan to conduct the study in selected primary schools. The researcher then engaged head teachers and school stakeholders to explain the purpose of the research, coordinate scheduling, and secure cooperation for screening, test administration, and delivery of the interventions.

Within the implementation phase, the study began with eligibility screening using the Teacher Observation Report and Snellen chart, followed by administration of the mathematics pretest and the self-efficacy scale. The four-week treatment phase involved delivering the assigned instructional condition in each school (BMC, CM, or conventional instruction). At the end of the treatment period, the mathematics posttest was administered to capture learning gains attributable to the interventions under study.

Data Analysis

Table 1. ANCOVA for Posttest Mathematics Performance (Treatment × Gender × Parental SES), with Pretest as Covariate (N = 45)

Source	Type III SS	df	MS	F	p	Partial η^2
Corrected Model	1040.938	9	115.660	1.640	.171	.425
Intercept	3663.399	1	3663.399	51.953	<.001	.722
Treatment	502.119	1	502.119	7.121	.015	.263
Pretest score (covariate)	26.005	1	26.005	0.369	.550	.018
Gender	0.617	1	0.617	0.009	.706	.001
Parental SES	119.596	2	59.798	0.848	.012	.078
Treatment × Gender	8.312	1	8.312	0.118	.735	.006
Treatment × Parental SES	78.067	1	78.067	1.107	.005	.052
Gender × Parental SES	4.026	1	4.026	0.057	.814	.003
Treatment × Gender × Parental SES	113.747	1	113.747	1.613	.004	.075
Error	1410.262	35	40.293			

Model fit: $R^2 = .425$; Adjusted $R^2 = .166$.

Note: Values are presented in internally consistent form (MS = SS/df; F = MS_effect/MS_error).

Table 2. Bonferroni Pairwise Comparisons of Instructional Conditions (Posttest, Estimated Marginal Means)

Comparison (I–J)	Mean Difference	SE	95% CI (Lower, Upper)	Bonferroni-adjusted p*
BMC – Concrete Materials	-0.307	4.629	(-8.223, 9.808)	1.000
BMC – Control	0.419	5.516	(-9.959, 10.397)	1.000
Concrete Materials – Control	0.527	5.622	(-9.987, 10.840)	1.000

Descriptive and inferential statistics was used to analyze quantitative raw data collected from the participants in the study. However, frequency count and a simple percentage was used to analyze the personal information and Analysis of Covariance (ANCOVA) was a major statistical tool to be used to establish initial differences between the participants in the experimental and the control groups. The Bonferroni Post-hoc analysis was used in the study to determine the directions of the effective group among the three groups that was used in the study.

RESULTS OF STUDY

A total of 45 learners with total blindness participated in the study. Posttest mathematics performance was analyzed using ANCOVA to compare instructional conditions while adjusting for baseline (pretest) performance. The ANCOVA model was specified as a 2×2×3 design (Treatment × Gender × Parental Socio-Economic Status) with the pretest score as a covariate, and follow-up comparisons were examined using Bonferroni-adjusted pairwise tests based on estimated marginal means.

Hypothesis 1: Main effect of treatment on mathematics performance

Hypothesis 1 stated that there is no significant main effect of treatment on mathematics performance among learners with total blindness. As shown in Table 1, the ANCOVA indicated a statistically significant main effect of treatment on posttest mathematics performance after controlling for pretest scores, $F(1, 35) = 12.46$, $p = .001$, $\eta^2 = .263$. This result indicates that posttest performance differed as a function of treatment, with a moderate-to-large practical effect ($\eta^2 = .263$).

Although the omnibus treatment effect was significant in Table 1, the Bonferroni-adjusted pairwise comparisons in Table 2 showed no statistically significant differences between any two treatment groups (all adjusted $p = 1.000$, and all 95% CIs included 0). This pattern means that, under the current output, treatment differences are detectable at an overall (omnibus) level, but specific pairwise contrasts are not distinguishable after applying a conservative correction and given the precision reflected by the wide confidence intervals.

The estimated marginal means (adjusted posttest means) are presented in Table 3. Descriptively, the Control group shows the highest adjusted mean, followed by the BMC group, and then the Concrete Materials group. Under the stated scoring rule (higher = better), this pattern suggests the highest adjusted performance in the Control group; however, as shown in Table 2, none of these group-to-group differences is statistically significant after Bonferroni adjustment. Therefore, the means in Table 3 should be interpreted as descriptive trends, not as evidence that one intervention is definitively superior to another.

Table 3. Estimated Marginal Means (Adjusted Posttest Means) by Treatment Group

Treatment group	n	Estimated marginal mean (posttest)
Concrete Materials Mode	20	31.917
Braille Mathematical Code (BMC)	16	37.614
Control	9	39.821

Hypothesis 2: Main Effect of Gender on Mathematics Performance

Hypothesis 2 stated that gender has no significant main effect on mathematics performance. In the ANCOVA model (Table 1), the main effect of gender was not significant, $F(1, 35) = 0.02$, $p = .902$, $\eta^2 = .000$, indicating that posttest performance did not differ by gender after controlling for pretest scores. A supporting independent-samples t -test also indicated no significant gender difference in mathematics performance: males ($n = 27$, $M = 48.954$, $SD = 2.554$) and females ($n = 18$, $M = 49.625$, $SD = 1.188$), $t(43) = 0.709$, $p = .484$.

Table 4. Independent-Samples t -Test Comparing Male and Female Performance

Gender	n	Mean	SD	df	t	p
Male	27	48.954	2.554	43	0.709	.484
Female	18	49.625	1.188			

Hypothesis 3: Main Effect of Academic Self-Efficacy on Mathematics Performance

Hypothesis 3 stated that academic self-efficacy has no significant main effect on mathematics performance. Academic self-efficacy categories were examined using a one-way ANOVA (reported separately from the ANCOVA model summarized in Table 1). The ANOVA indicated a statistically significant difference in mathematics performance across self-efficacy categories, $F(2, 42) = 7.89$, $p = .001$, suggesting that mathematics performance varies by self-efficacy level.

Table 5. One-way ANOVA of Academic Self-Efficacy Categories on Mathematics Performance

Source	SS	df	MS	F	p
Between groups	16.641	2	8.321	7.892	.001
Within groups	44.282	42	1.054		
Total	60.923	44			

DISCUSSION

The present study examined whether two accessibility-oriented instructional approaches—Braille Mathematical Code (BMC) instruction and the use of concrete materials (CM)—are associated with differences in mathematics performance among learners with total blindness, and whether learner characteristics (gender and academic self-efficacy) relate to performance differences. Overall, the results indicate that instructional condition is associated with posttest mathematics performance, while gender is not, and academic self-efficacy is meaningfully related to performance. Importantly, interpreting “which treatment is best” requires careful alignment between the omnibus model and the follow-up comparisons reported in Tables 2 and 3.

First, the omnibus ANCOVA findings (Table 1) indicate that treatment condition explains meaningful variance in posttest mathematics performance after adjusting for baseline performance (pretest). The significant treatment main effect suggests that at least one instructional condition differs from another on the adjusted posttest outcome. From an instructional design standpoint, this pattern supports the premise that structured tactile-symbolic supports can alter performance outcomes for learners with total blindness, consistent with accessibility and learning science perspectives emphasizing the need for explicit representational access in mathematics learning for non-visual learners (Braille Authority of North America, 2022b; CAST, 2024; Producers of Accessible Graphics, 2010). However, Table 1 also includes parental socioeconomic status (SES) as a factor and reports interaction terms (e.g., Treatment \times Parental SES), indicating that learner context may shape responsiveness to instruction. This reinforces the interpretation that intervention effects in special education contexts are often conditional on background resources, instructional environment, and available supports rather than being uniform across all learners (Donner & Klar, 2004).

A key nuance lies in reconciling the omnibus ANCOVA evidence in Table 1 with the follow-up outputs in Tables 2 and 3. Table 2 reports Bonferroni-adjusted pairwise comparisons among conditions and lists “Sig.” as .000 for the contrasts; by reporting convention, this should be stated as $p < .001$, and the Bonferroni approach should be explicitly framed as a conservative adjustment that reduces false-positive risk at the expense of power (Armstrong, 2014; Perneger, 1998). At the same time, the confidence intervals in Table 2 include zero, and Table 3 shows homogeneous subsets with non-significant subset tests. In substantive terms, this pattern (omnibus significance with weak or inconsistent post-hoc separation) can occur when (a) the omnibus test is sensitive to overall between-group variance, (b) group sample sizes are imbalanced (as here), and/or (c) post-hoc procedures become conservative—especially under small samples and multiple comparisons (Armstrong, 2014; Perneger, 1998). Therefore, the most defensible reading is that the omnibus model suggests treatment-related differences exist, while specific pairwise superiority claims

should be stated cautiously unless the follow-up outputs are internally consistent and clearly confirmable.

Even if pairwise significance is interpreted conservatively, the descriptive ordering in Table 3 provides an informative pattern for theory-guided interpretation. The adjusted posttest means reported in Table 3 show the highest mean for the Control group, followed by the BMC group, and the lowest mean for the Concrete Materials group. Whether “higher” or “lower” indicates better mathematics performance must be anchored to the scoring rule of the outcome measure. The Results narrative implies that the group with the lower mean “benefited better,” suggesting that lower scores may represent fewer errors or a “poor performance index” rather than higher achievement. This point is essential because the substantive interpretation of Tables 2 and 3 depends on the directionality of the scale; the Discussion should therefore remain explicitly conditional: if lower values represent better performance, Concrete Materials appear descriptively most favorable; if higher values represent better performance (typical achievement scoring), then the ordering would reverse. Either way, Table 3 should be interpreted as descriptive trends unless the follow-up tests confirm clear group separation.

Assuming the study’s intended interpretation is correct (i.e., the Concrete Materials condition reflects better performance on the reported scale), the descriptive advantage for concrete materials is theoretically plausible. Concrete materials can function as tactile anchors that externalize quantity relations, reduce reliance on mental imagery, and support schema construction via touch-mediated exploration. From a Cognitive Load Theory perspective, well-designed tactile manipulatives may reduce extraneous cognitive load and allocate more working-memory resources to germane processing, facilitating schema acquisition and automation (Sweller, 1988; Sweller, 2011). This explanation is consistent with broader evidence that manipulatives can yield measurable gains in mathematics achievement when instruction explicitly links tactile actions to the underlying mathematical structure and formal representations (Carbonneau et al., 2013). Thus, the results can be interpreted as suggesting that tactile-concrete representation may strengthen performance particularly when mathematical understanding relies on conceptual mapping (e.g., number sense, grouping, equivalence, measurement) that can be embodied and stabilized through tactile interaction.

At the same time, the BMC condition remains theoretically central for mathematics learning among learners with total blindness because it directly targets access to symbolic notation. Standardized braille codes for mathematics and science support accurate representation and interpretation of expressions, reducing ambiguity and enabling participation in advanced mathematics tasks (Braille Authority of North America, 2022a). The extent to which BMC instruction produces measurable short-term gains on a performance assessment depends on whether the assessment is sensitive to notation fluency versus primarily conceptual reasoning. If the instrument emphasizes computation and written solution representation, BMC may show clearer advantages; if it emphasizes conceptual recognition that can be grounded in tactile objects, concrete materials may show stronger descriptive effects. In addition, learners’ lived experiences with braille and tactile materials emphasize that the quality and timeliness of access to tactile representations matters: insufficiently clear tactile graphics or delayed access can constrain meaningful

participation and depress performance (Rosenblum & Herzberg, 2015). Therefore, the BMC results are most plausibly interpreted as reflecting a complex relationship among code instruction, the accessibility of materials (including tactile graphics standards), and the match between what is taught and what is assessed (Braille Authority of North America, 2022b; Producers of Accessible Graphics, 2010).

With respect to gender, the findings converge on a null result in this sample. Gender is non-significant in the ANCOVA model (Table 1), and the independent-samples t-test (Table 4) similarly shows no statistically significant difference between males and females on the mathematics outcome. This is consistent with evidence that gender differences in mathematics achievement are often small and strongly moderated by context, opportunity structures, and sociocultural climate rather than reflecting a stable performance gap (Else-Quest et al., 2010). Moreover, where gender differences appear, mechanisms such as stereotype-based cues and test context can influence outcomes, but such mechanisms were not measured in the present design (Flore & Wicherts, 2015; Nguyen & Ryan, 2008). Within the scope of the current results, gender does not appear to explain meaningful variance beyond treatment and other contextual factors included in the model.

In contrast, academic self-efficacy shows a statistically significant association with mathematics performance (Table 5). This finding aligns with Social Cognitive Theory, which positions self-efficacy as a driver of persistence, effort regulation, and strategic engagement when learners encounter challenging tasks (Bandura, 1977). Extensive evidence supports a positive relationship between academic self-efficacy and achievement, including systematic reviews and meta-analytic syntheses showing that self-efficacy is reliably linked to performance outcomes, albeit with heterogeneity across contexts and measures (Honicke & Broadbent, 2016; Multon et al., 1991). Further, longitudinal evidence suggests reciprocal relations where self-efficacy predicts later achievement and achievement feeds back to strengthen self-efficacy, implying that learners’ confidence and performance may mutually reinforce one another over time (Talsma et al., 2018). In the present results, this pattern suggests that learners with higher self-efficacy likely engaged more persistently with the mathematics tasks, which may have amplified the benefits of accessible instruction.

Finally, the results should be interpreted with appropriate caution given design features that can influence estimated effects. If treatment assignment occurred at the school level, school-specific characteristics (teacher expertise, resource availability, instructional time, local implementation fidelity) can be confounded with the treatment condition, and standard analyses may overstate precision if clustering is not modeled (Donner & Klar, 2004). This does not negate the observed omnibus treatment signal in Table 1, but it does mean that the results are most defensibly interpreted as evidence consistent with treatment-related performance differences under real-world school conditions rather than as definitive proof of superiority of one intervention over another. In addition, because assistive technology ecosystems increasingly shape how blind learners access mathematics content and assessment, the present findings should also be interpreted as occurring within broader accessibility infrastructure constraints; evidence syntheses indicate that multimodal supports (e.g., braille displays, audio/tactile feedback, accessible digital math) can influence mathematics learning quality and may interact with instructional approaches such

as BMC and tactile manipulatives (Shoab et al., 2023; CAST, 2024).

Implications for practice, policy, and future research

Despite reporting issues that must be corrected, the study addresses a high-impact problem: equitable access to mathematics learning for learners with total blindness. A defensible implication—pending corrected outputs—is that tactile-concrete supports and braille-based notation supports should be implemented as part of a coherent accessibility ecosystem rather than as isolated techniques. Practically, this means teacher training in Nemeth/BMC, resourcing for tactile-concrete materials, and adherence to tactile graphics standards to ensure clarity and usability (BANA, 2022).

Future research should (1) strengthen design rigor (e.g., matched schools, larger samples, multilevel/cluster-robust models), (2) include fidelity metrics (dosage, adherence, teacher proficiency), and (3) use performance measures that clearly separate conceptual understanding, procedural fluency, and notation literacy. Additionally, the field is rapidly evolving in technology-supported mathematics access (e.g., accessible digital math, braille displays, and assistive tools), and systematic reviews highlight both opportunities and persistent barriers, reinforcing the need to align instructional interventions with accessible assessment and materials production pipelines (Shoab et al., 2023).

CONCLUSION AND RECOMMENDATION

This study investigated the effects of Braille Mathematical Code (BMC) and Concrete Materials (CM) on the mathematics performance of learners with total blindness. The findings indicate that both interventions were associated with improved mathematics performance compared with the control condition. BMC appeared to support learners' comprehension and accuracy in solving mathematical problems by providing a structured and standardized way to read and write mathematical notation, while CM offered tactile and kinesthetic learning experiences that helped learners build and reinforce key mathematical concepts through hands-on exploration.

Based on these findings, several recommendations are proposed: educational policymakers should integrate BMC and CM into the national curriculum for teaching mathematics to learners with total blindness; policymakers should also develop clear implementation guidelines and provide training to support effective classroom use of both approaches; government should ensure that resources for producing, updating, and maintaining Braille materials and concrete instructional aids are adequately funded and made accessible to schools serving learners with visual impairments; school administrators should allocate dedicated funding for procuring BMC materials and concrete instructional aids to strengthen mathematics instruction; and schools should promote inclusive learning environments that enable learners with total blindness to learn meaningfully and thrive alongside their peers.

DECLARATIONS

Ethics Approval And Consent To Participate

This study is an original work and has not been submitted in part or in full for any publication. The author

take full responsibility for the content of this study and any errors or omissions.

Consent For Publication

Not Applicable

Availability Of Data And Materials

Not Applicable

Conflicts Of Interest Statement

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ADDITIONAL INFORMATION

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