

Language as a Mediator of Learning: A Bayesian Multilevel Analysis of Multilingual Mathematics Classrooms in Zambia

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Abstract

Persistent linguistic inequalities continue to constrain mathematics learning in Zambia, where learners transition from familiar local languages to English as the medium of instruction. This study investigated how language functions as a mediator of learning across learners, classrooms, and schools using Bayesian multilevel modelling. A cross-sectional sample of 1,284 learners nested within 54 classrooms and 18 schools completed assessments of L1 and L2 proficiency, working memory, mathematics achievement, and measures of classroom language practices and school-level multilingual support. Four hierarchical Bayesian models were estimated using MCMC procedures with weakly informative priors, model comparison via WAIC/LOOIC, and posterior predictive checks. Results demonstrated strong evidence that L2 proficiency ($\beta = 0.42$, 95% CrI > 0) and L1 proficiency ($\beta = 0.18$, CrI > 0) significantly predicted mathematics achievement, with working memory exerting additional cognitive influence. Supportive teacher language practices translanguageing, strategic code-switching, L1 explanation, and learner talk—yielded robust positive effects, including cross-level interactions showing amplified benefits for learners with low English proficiency. Linguistic coherence and teacher–learner L1 match positively shaped performance, whereas linguistic diversity produced negative effects only in classrooms lacking multilingual scaffolding. School-level policy implementation, availability of local-language materials, and institutional support for multilingual pedagogy exerted indirect impacts through classroom practices. Findings affirm that language is a powerful mediator of mathematical understanding across ecological levels. Strengthening linguistically responsive pedagogy, classroom discourse, and institutional language-in-education practices is essential for improving mathematics learning in multilingual systems.

Keywords: Multilingual Education, Mathematics Achievement, Bayesian Multilevel Modelling, Translanguageing, Linguistic Diversity, Language Proficiency, Cognitive Load, Zambia

1. Introduction

Language has increasingly become a focal point in global debates about educational equity, cognitive access, and effective pedagogy. Across the world, and particularly in multilingual regions of Africa, scholars and policymakers continue to grapple with a fundamental question: How does language shape the learning process, especially in conceptually demanding subjects such as mathematics? As education systems confront persistent inequalities in learning outcomes, multilingual education is being

re-examined not merely as a linguistic issue but as a central driver of epistemic access, cognitive development, and instructional quality. These debates are especially pronounced in Sub-Saharan Africa, where the tension between local linguistic identities and the dominance of former colonial languages remains an enduring feature of schooling.

Globally, research has consistently shown that language is not a passive vessel for transmitting knowledge but an active mediator

that shapes how learners think, reason, and construct meaning. Theoretical frameworks in cognitive psychology highlight that language influences working memory, attention, conceptual processing, and problem-solving skills that are foundational for mathematics learning. From an instructional perspective, language structures classroom discourse, guides teacher explanations, and frames opportunities for learner participation. Socioculturally, language embodies identity, power relations, and community knowledge systems, shaping how learners position themselves in learning environments and how they interact with both mathematical ideas and peers. In multilingual classrooms, these cognitive, instructional, and sociocultural dimensions intersect in powerful ways, influencing not only academic performance but also learners' confidence, participation, and sense of belonging.

The African context amplifies these dynamics. Most education systems in Africa—including Zambia—operate in a multilingual reality where children enter school with rich linguistic repertoires rooted in indigenous languages. Yet instruction, particularly beyond lower primary, is conducted predominantly in English or other colonial languages. This linguistic transition creates discontinuities in learners' cognitive access to mathematical concepts and often places them at a disadvantage when solving problems, interpreting tasks, or engaging in classroom discussions. While policy reforms across the continent have encouraged mother-tongue instruction in the early grades, implementation remains uneven, and many learners experience mathematics primarily through a language they are still acquiring. African scholars have therefore emphasized the need for pedagogies that harness multilingual resources rather than suppress them, arguing that learners' home languages can serve as cognitive bridges for understanding abstract concepts.

Within this context, mathematics presents unique challenges and opportunities. Mathematics is often perceived as a universal language, yet its learning is deeply linguistic: understanding word problems, interpreting symbolic expressions, constructing arguments, and articulating reasoning all depend on language proficiency. In multilingual classrooms, learners frequently engage in Translanguaging strategically moving between languages to make sense of mathematical ideas. While Translanguaging can enhance comprehension, teachers often lack structured guidance on how to use it effectively, and its benefits remain poorly quantified. Additionally, diverse language backgrounds within a single classroom can lead to varied levels of participation, differential access to teacher explanations, and widened achievement gaps. These complexities underscore the urgent need for empirical evidence that captures how language mediates the mathematics learning process across learners, teachers, and schools.

Despite decades of research, the relationship between language and mathematics learning in Zambia remains underexplored using advanced quantitative methods. Existing studies largely draw from qualitative evidence or conventional statistical approaches that do not fully account for the hierarchical structure of educational data. However, learning occurs within nested systems—learners in classrooms, classrooms within schools each with linguistic

characteristics that may influence mathematical outcomes. Traditional analyses obscure these cross-level interactions and fail to capture the variability and uncertainty inherent in multilingual learning environments.

Bayesian multilevel modelling offers a rigorous and innovative methodological lens to examine these dynamics. Unlike frequentist models, Bayesian approaches allow for the incorporation of prior knowledge, provide richer uncertainty estimates, and account for heterogeneity across individuals, classrooms, and schools. This is particularly relevant for multilingual contexts where linguistic influences on learning are complex, probabilistic, and interactive. Bayesian models make it possible to estimate not only the direct effects of language proficiency but also the indirect pathways through which teacher language practices, classroom linguistic composition, and school-level policies shape mathematics learning.

Zambia provides a compelling context for such an investigation. With 72 languages and a national policy that transitions learners from local languages in lower primary to English in upper primary and secondary school, mathematics classrooms operate at the intersection of linguistic diversity and policy complexity. Teachers often navigate multiple languages simultaneously, using translanguaging, code-switching, and multilingual explanations to bridge comprehension gaps. Yet, the consequences of these practices remain insufficiently understood in quantitative terms. Given Zambia's emphasis on improving mathematics performance at national and regional levels, understanding how language mediates learning is both timely and policy-relevant.

Against this backdrop, this article examines how language functions as a mediator of learning in multilingual mathematics classrooms in Zambia using Bayesian multilevel analysis. By integrating theoretical insights from cognitive psychology, sociocultural theory, multilingual education, and advanced statistical modelling, the study provides a nuanced, multi-layered understanding of the linguistic factors shaping mathematical learning. It moves beyond deficit narratives to highlight language as a resource—and positions multilingualism as a central, not peripheral, component of effective mathematics instruction in Zambia and similar African contexts.

This introduction establishes the intellectual, empirical, and methodological foundations for a study that reconceptualizes language not as a barrier, but as a dynamic mediator of mathematical understanding. Through advanced Bayesian modelling, the article seeks to generate robust, policy-relevant evidence capable of informing teacher training, curriculum design, language-in-education policy implementation, and classroom practice in multilingual education systems.

1.1. Problem Statement

Mathematics learning in Zambia continues to be hindered by persistent linguistic inequalities arising from the misalignment between learners' home languages and the language of instruction.

Although the 2013 Zambian Education Curriculum Framework mandates the use of a familiar local language as the medium of instruction in Grades 1–4 before transitioning to English in Grade 5, empirical evidence consistently shows that this transition introduces significant comprehension barriers that undermine learners’ engagement and conceptual understanding in mathematics [1]. A national UNICEF study on language of instruction found that many Zambian learners struggle academically when instruction shifts to English, with the report affirming that children perform best when taught in a language they understand and noting that uneven implementation of the local-language policy, limited teacher preparation, and inadequate multilingual resources continue to impede mathematics learning [2]. Similarly, the PISA for Development (PISA-D) Zambia National Report by the Examinations Council of Zambia indicates that a substantial proportion of learners found it difficult to interpret mathematics items due partly to low English reading proficiency, with linguistic demand identified as a barrier to mathematical reasoning [3]. These national patterns are reinforced by regional and local empirical studies, such as Nkamba and Mwanza’s Muchinga-based research showing that the use of familiar languages in explaining mathematical and scientific concepts improves learner participation, reduces anxiety, and enhances conceptual clarity. Broader African scholarship also confirms that language proficiency in the language of instruction is a strong predictor of mathematics performance [4]. Despite this evidence, the Zambian literature remains limited by methodological constraints: most studies rely on qualitative designs or single-level quantitative analyses that fail to capture multilevel linguistic dynamics across learners, classrooms, and schools. Furthermore, no study in Zambia or Southern Africa has applied Bayesian multilevel modelling, despite its suitability for analysing complex, nested educational data and generating robust probabilistic insights [5]. As a result, Zambia remains underrepresented in global quantitative multilingual-education research, and policymakers lack the nuanced, multilevel evidence required to design linguistically responsive mathematics instruction, teacher training, and assessment reforms. This study addresses this critical gap by employing Bayesian multilevel modelling to examine how language mediates mathematics learning in multilingual Zambian classrooms, thereby generating rigorous, context-sensitive evidence to inform equitable language-in-education policy and practice.

1.2. Purpose of the Study

The purpose of this study is to investigate how language functions as a mediator of mathematics learning outcomes within Zambia’s multilingual classroom environments by applying Bayesian multilevel modelling. Specifically, the study seeks to quantify the extent to which learner language proficiency, teacher language practices, and classroom linguistic composition jointly influence mathematical performance across hierarchical levels of the education system. By integrating linguistically informed theoretical perspectives with advanced Bayesian hierarchical analytics, the study aims to generate robust, context-sensitive evidence that illuminates the complex, cross-level pathways through which language shapes mathematical reasoning, comprehension, and

achievement in multilingual settings. Ultimately, the study seeks to provide methodologically rigorous insights capable of informing linguistically responsive instructional practices, teacher preparation, and language-in-education policy reform.

1.3. Research Questions

- a) To what extent does learners’ proficiency in the language of instruction influence their mathematics learning outcomes in multilingual classrooms?
- b) How do teachers’ language practices affect learners’ mathematics performance in multilingual settings?
- c) How does classroom linguistic composition relate to variations in mathematics achievement?
- d) To what extent do school-level language in-education practices influence mathematics learning outcomes?

1.4. Hypotheses

H1. Learners with higher proficiency in the language of instruction are more likely to demonstrate higher mathematics learning outcomes than learners with lower proficiency.

H2. Classrooms in which teachers effectively use supportive language practices will show higher mathematics performance than classrooms where such practices are limited.

H3. Classrooms with more linguistically coherent or supportive language environments will exhibit higher mathematics achievement than classrooms with high linguistic heterogeneity.

H4. Schools with stronger implementation of language-in-education practices and better support for multilingual teaching will demonstrate higher overall mathematics learning outcomes compared to schools with weak implementation.

1.5. Significance of the Study

This study is significant for three interrelated reasons—its theoretical contribution, methodological advancement, and policy relevance within Zambia’s multilingual education landscape. First, the study offers important theoretical value by deepening understanding of language as a mediator of learning through the lenses of sociocultural theory, linguistic relativity, and cognitive load theory. Sociocultural theory positions language as a central tool for meaning-making, suggesting that mathematical understanding is constructed through culturally situated discourse practices. Linguistic relativity highlights how linguistic structures shape cognitive processing, implying that learners’ reasoning in mathematics is influenced by the languages available to them. Cognitive load theory reinforces this by demonstrating that unfamiliar instructional languages increase extraneous cognitive load, reducing the mental resources available for conceptual understanding. By integrating these theoretical perspectives, the study advances a more holistic explanation of how linguistic factors influence mathematical cognition and performance in multilingual contexts.

Second, the study provides methodological innovation by applying Bayesian multilevel modelling an approach seldom used in African educational research—to the analysis of multilingual mathematics classrooms. While existing studies in Zambia and the Southern African region rely predominantly on qualitative methods or single-level analyses, Bayesian multilevel modelling enables the estimation of cross-level effects and uncertainty with greater precision. This approach captures the hierarchical nature of educational data, allowing the study to model how learner-level language proficiency interacts with teacher practices, classroom linguistic composition, and school-level policy implementation. The introduction of Bayesian inference into this research domain represents a methodological advancement with the potential to strengthen the robustness and credibility of empirical findings in African education systems.

Third, the study holds significant policy relevance for ongoing debates on language-in-education reforms in Zambia. As the country continues to implement and refine its local language and English transition policies, empirical evidence on the linguistic factors that shape mathematics learning is urgently needed. The study provides nuanced, multilevel insights that can inform curriculum design, teacher education programmes, resource allocation, and assessment practices. By identifying how language mediates learning outcomes across learners, classrooms, and schools, the findings have the potential to guide the development of more equitable, linguistically responsive instructional strategies. Ultimately, the study contributes to national and regional efforts to strengthen learning outcomes by ensuring that language policies are grounded in rigorous evidence rather than assumptions.

2. Theoretical and Conceptual Framework

2.1. Sociocultural Theory by Vygotsky

Sociocultural Theory, developed by Lev Vygotsky, positions learning as a fundamentally social and culturally embedded process in which language serves as the primary mediational tool for cognitive development. According to Vygotsky, individuals do not acquire knowledge in isolation; rather, they learn through guided participation, interaction, and cultural tools that structure thinking. In educational contexts and particularly in mathematics classrooms language is the most powerful of these tools because it both communicates knowledge and shapes the mental processes through which learners internalize concepts.

A central tenet of Sociocultural Theory is the idea of language as a mediational tool. Vygotsky argued that language functions not merely as a vehicle for expressing thought but as the cognitive instrument that organizes, regulates, and transforms thinking. In multilingual mathematics classrooms, this means that the languages learners bring from home, the language the teacher uses in instruction, and the linguistic practices that emerge during interaction all mediate how learners process and understand mathematical ideas. When learners engage with mathematics through a familiar language, they are better able to articulate reasoning, negotiate meaning, and participate in problem-solving discussions. Conversely, when instruction is delivered in an

unfamiliar language, learners face an added cognitive burden that constrains their ability to engage meaningfully with abstract concepts.

Sociocultural Theory also emphasizes cognitive development through language-mediated interactions. Vygotsky proposed that higher-order thinking develops through socially mediated activities within the Zone of Proximal Development (ZPD) the space in which learners can achieve more with support from a knowledgeable other than they can independently. In mathematics education, interactions between teachers and learners asking questions, explaining procedures, reasoning aloud, debating strategies become vehicles through which cognitive development unfolds. These interactions are shaped by the language used: the clarity of teacher explanations, the linguistic accessibility of tasks, the flexibility of switching between languages, and the classroom norms governing discourse.

In multilingual settings such as Zambia, the sociocultural perspective highlights that learning is not purely individual but is distributed across linguistic, cultural, and social resources. When teachers draw on learners' familiar languages, they enhance learners' ability to operate within their ZPD, foster participation, and reduce anxiety associated with language barriers. This promotes deeper conceptual understanding and facilitates the movement from social interaction to internalized mathematical reasoning. Thus, Sociocultural Theory underscores the pivotal role of language in mediating mathematical cognition and provides a strong theoretical foundation for examining how multilingual instructional practices shape learning outcomes.

Building on Vygotsky's assertions, language in multilingual mathematics classrooms becomes more than a conduit for instruction; it is the central mediational means through which learners' access, interpret, and internalize mathematical concepts. When teachers employ familiar languages or fluid multilingual practices, they create linguistic scaffolds that support learners within their Zone of Proximal Development, enabling them to engage with tasks that would otherwise be cognitively inaccessible. Through dialogue, questioning, peer interaction, and teacher-led explanation, learners construct meaning collaboratively and gradually transform these shared linguistic experiences into independent mathematical reasoning. In this way, cognitive development is inseparable from the quality and accessibility of language-mediated interactions. The linguistic resources made available in the classroom whether through translanguaging, code-switching, or structured mathematical discourse shape not only how learners communicate ideas but also how they mentally organize, process, and retain mathematical knowledge. Consequently, understanding the mediational role of language is essential for explaining the cognitive pathways through which learners in multilingual settings develop mathematical proficiency.

2.2. Cummins' Linguistic Interdependence Hypothesis

Cummins' Linguistic Interdependence Hypothesis (LIH) provides an important theoretical link between learners' first-language (L1)

proficiency and their academic performance in a second language (L2), such as English. The hypothesis proposes that underlying cognitive and linguistic skills developed in L1 such as vocabulary knowledge, conceptual understanding, and reasoning strategies—transfer to L2 and support learning across subjects. In multilingual mathematics classrooms, this means that learners who have strong literacy and conceptual foundations in a familiar language are better positioned to access and understand mathematical tasks presented in English. Conversely, limited L1 development can restrict learners' ability to make sense of L2 mathematical discourse, leading to increased cognitive strain and reduced achievement. By emphasizing the interdependence of linguistic skills across languages, Cummins' theory highlights why supporting learners' L1 is not a hindrance but a critical asset for strengthening mathematical understanding and academic success in multilingual contexts such as Zambia.

3. Conceptual Model

The conceptual model guiding this study proposes that language functions as a central mediating mechanism through which learner-level, classroom-level, and school-level factors influence mathematics learning outcomes in multilingual Zambian classrooms. At the learner level, variables such as proficiency in

the language of instruction and prior literacy skills directly shape learners' ability to comprehend mathematical discourse, interpret tasks, and engage in problem-solving. These learner characteristics are embedded within classroom-level processes, including teachers' language practices (e.g., translanguaging, code-switching, and use of familiar languages), the linguistic composition of the classroom, and the overall discourse environment. These classroom factors can strengthen or weaken the mediating influence of language by shaping how mathematical ideas are communicated and negotiated during instruction.

At the school level, implementation of language-in-education policies, availability of linguistic resources, and institutional support for multilingual teaching further condition how language is used in pedagogical practice. The model assumes that these higher-level structures moderate the relationships observed at lower levels. Collectively, the framework conceptualizes mathematics achievement as the product of a multi-layered system in which language simultaneously mediates and moderates cognitive access, instructional clarity, and discourse-based learning.

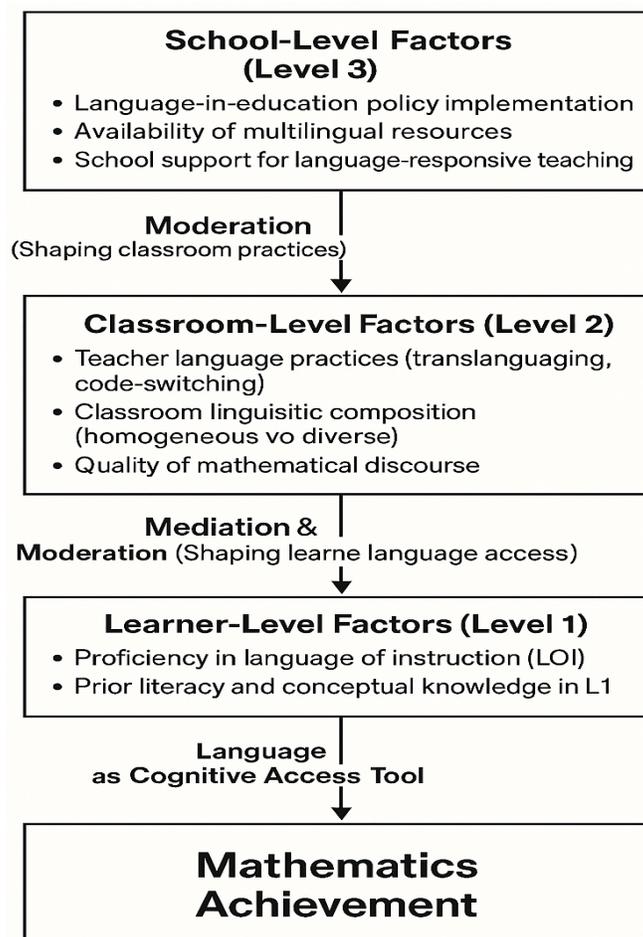


Figure 1: Conceptual Model

4. Literature Review

4.1. Multilingual Education and Mathematics Achievement

Global research consistently demonstrates that language plays a decisive role in shaping learners' access to mathematics. UNESCO and World Bank reports show that children taught in familiar languages attain stronger foundational skills and exhibit greater mathematical comprehension than those taught exclusively in unfamiliar languages [6]. This aligns with international findings that linguistic accessibility reduces cognitive burden, strengthens conceptual reasoning, and improves performance in subjects that require abstract thinking such as mathematics. The UNESCO-supported PISA for Development assessments further reveal that in multilingual, low-income contexts, linguistic barriers account for a significant portion of variance in mathematics item performance [3].

Across Africa, scholarship has increasingly focused on the intersection of multilingualism and mathematics learning. Essien's landscape analysis of early-grade mathematics in South Africa found that language is central to how learners construct mathematical meaning, particularly within linguistically diverse classrooms where learners depend on familiar languages to negotiate abstract concepts [7]. Expanding this view, Essien's systematic review of seventy-five studies across multiple African countries confirms that multilingual classrooms present both challenges and opportunities: while English or French dominance constrains access for many learners, strategically incorporating African languages supports conceptual clarity, participation, and problem solving [8]. These continental insights reinforce earlier South African studies demonstrating that code-switching and translanguaging serve as essential pedagogical tools for mediating mathematical meaning in multilingual contexts [9].

In Zambia, multilingual education remains central to mathematics pedagogy, especially following the 2013 education policy mandating the use of familiar local languages (e.g., Cinyanja, Icibemba, Silozi, Chitonga) in Grades 1–4. However, the UNICEF Language of Instruction Study notes persistent implementation challenges: teachers inconsistently apply the policy, many learners still encounter English too early, and schools lack materials in local languages. These linguistic misalignments contribute to difficulties in mathematical comprehension and reduced learner engagement.

Empirical evidence from multilingual mathematics classrooms in Zambia reinforces these concerns. A study conducted in Muchinga Province by Nkonde et al. found that using familiar local languages as the medium of instruction significantly enhanced learner participation, reduced anxiety, and improved concept assimilation in mathematics and science lessons [10]. Learners were more willing to ask questions and demonstrated deeper reasoning when taught in a language they understood well. Similarly, Sampa reports that incorporating Bemba alongside English as the medium of instruction improved learners' ability to interpret mathematical explanations and vocabulary, showing that bilingual approaches can facilitate access to mathematical discourse.

Classroom-level research deepens this understanding. Mambwe and Ndhlovu, studying Grade Four mathematics classrooms in Zambia, document extensive use of code-switching and translanguaging by teachers who navigate between English and familiar Zambian languages to clarify mathematical ideas [11]. Their findings show that learners rely heavily on local languages during peer discussions and problem solving, even when official instructional policy prescribes a single medium. Comparable evidence from Kenya, Uganda, and Tanzania indicates that learners use familiar languages to make sense of mathematical procedures and to negotiate meaning during group work [7].

Synthesizing global, African, and Zambian evidence reveals a consistent conclusion: multilingual mathematics instruction, when grounded in learners' familiar languages and integrated with disciplined instructional strategies, improves comprehension, participation, and reasoning. However, the literature is dominated by qualitative case studies and small-scale investigations. There remains limited large-scale, quantitative research—especially using Bayesian multilevel modelling to examine how language mediates mathematics achievement across learners, classrooms, and schools. Addressing this methodological gap is essential for producing rigorous, generalizable evidence that can guide Zambia's language-in-education reforms and mathematics curriculum planning.

4.2. Language Proficiency and Mathematical Cognition

Language proficiency plays a central role in mathematical cognition because many mathematical processes far from being purely numerical are linguistically mediated. Research in cognitive psychology demonstrates that working memory is strongly influenced by linguistic processing demands, and when learners must interpret content in an unfamiliar language, the added linguistic load reduces available cognitive resources for mathematical reasoning [12,13]. According to Swanson and colleagues, complex mathematical tasks draw heavily on the phonological loop and central executive components of working memory, both of which are sensitive to language proficiency. When learners confront mathematical explanations or instructions in a language they do not fully command, a significant portion of their working-memory capacity is consumed by decoding linguistic information rather than processing mathematical concepts [14]. This reduces the cognitive resources available for tasks such as multi-step reasoning, symbolic manipulation, and problem-solving. Studies on multilingual learners further show that language-related working-memory load is especially high when transitioning from home languages to a school language such as English, a dynamic observed across African contexts and relevant to multilingual settings like Zambia [15]. As a result, linguistic barriers—not conceptual inability often account for difficulties in mathematical processing among learners navigating multiple languages.

Language proficiency is also closely linked to symbolic understanding, a foundational component of mathematical cognition. Mathematical symbols such as operational signs,

algebraic variables, and relational symbols gain meaning through linguistic labels and verbal explanations, making language central to how learners construct symbolic–conceptual links [16]. Learners who lack proficiency in the language of instruction often struggle to interpret these linguistic explanations, which limits their ability to attach accurate meanings to mathematical symbols and procedures. As a result, they may depend on rote memorisation rather than developing deep conceptual understanding—a pattern widely observed among learners studying mathematics in a second or unfamiliar language [17]. Research from multilingual classrooms further shows that when learners are encouraged to use familiar languages to articulate symbolic relationships, justify steps, and explain representations, they demonstrate more flexible reasoning and stronger representational fluency than when restricted to an unfamiliar instructional language [9,18]. These findings underscore that symbolic reasoning in mathematics is fundamentally mediated by linguistic accessibility, and that multilingual pedagogies can enhance learners’ conceptual engagement with mathematical representations.

Another critical area where language proficiency intersects with mathematical cognition is word-problem interpretation. Word problems require learners to translate verbal descriptions into mathematical structures, identify relevant information, and map linguistic cues onto operations. A substantial body of research shows that this linguistic mathematical translation process is highly sensitive to language proficiency and to the complexity of the verbal text [13,19]. When the language of the problem is not fully accessible, learners are more likely to misinterpret key relational terms (such as *more than*, *less than*, *altogether*), overlook or misunderstand contextual cues, and struggle to select appropriate operations, not because they lack mathematical competence but because linguistic barriers obscure the underlying problem structure [15]. Studies with multilingual and emergent bilingual learners have consistently found that simplifying the linguistic load of word problems—without changing their mathematical content or allowing learners to engage with problems in a familiar language improves performance, indicating that low achievement on word problems in multilingual contexts often reflects language processing difficulties rather than conceptual deficits [15,19].

The literature underscores that mathematical cognition is profoundly language-dependent. Working-memory load, symbolic reasoning, and word-problem interpretation all hinge on linguistic proficiency. In multilingual education systems like Zambia’s, where learners navigate between home languages and English, understanding how language proficiency shapes cognitive processing is essential for improving mathematics achievement. This theoretical and empirical foundation reinforces the importance of treating language not as a peripheral factor but as a core determinant of learners’ cognitive access to mathematics.

4.3. Classroom Linguistic Diversity and Teacher Challenges

Multilingual classrooms are inherently complex instructional spaces, and linguistic diversity significantly shapes how teachers manage mathematical teaching and learning. In Zambia and many

African countries, mathematics classrooms often include learners with varied linguistic backgrounds, varying proficiency in the language of instruction, and distinct cultural–linguistic repertoires. This diversity compels teachers to adopt flexible strategies to ensure cognitive access to mathematical ideas and maintain meaningful participation. Research from multilingual contexts shows that teachers frequently rely on Translanguaging practices the strategic use of multiple languages to scaffold understanding as a way of bridging linguistic gaps and making mathematical discourse more accessible. In her seminal work, García describes Translanguaging as a pedagogical approach that leverages learners’ full linguistic repertoires for meaning-making, while African studies demonstrate that translanguaging enables learners to engage deeply with mathematical concepts by reducing linguistic barriers and fostering collaborative sense-making [9,20,21].

Closely related to translanguaging is code-switching, a widespread pedagogical practice in multilingual mathematics classrooms. Code-switching occurs when teachers alternate between the language of instruction and a familiar local language to clarify vocabulary, simplify explanations, or emphasize key mathematical relationships. Research in South Africa and Zambia shows that code-switching serves as an essential instructional tool rather than a sign of linguistic deficiency [11,18,22]. It allows teachers to maintain lesson flow, negotiate mathematical meaning, and ensure that learners understand abstract or linguistically dense mathematical terminology. However, these studies also note that teachers often code-switch in unsystematic ways, influenced by classroom pressures, learners’ comprehension signals, and teachers’ own linguistic comfort levels.

Beyond Translanguaging and code-switching, teachers must make additional instructional adaptations to accommodate linguistic diversity. These adaptations may include simplifying linguistic structures of mathematical explanations, rephrasing word problems, using visual or concrete representations, grouping learners by language proficiency, or pausing to translate relational terms. Probyn argues that such adaptations reflect teachers’ attempts to balance curriculum expectations with learners’ linguistic realities [21]. However, research also highlights the challenges teachers face: limited training in multilingual pedagogy pressure to adhere to monolingual English-based policies, lack of instructional materials in local languages, and concerns that using familiar languages may slow learners’ acquisition of English academic registers [9,18].

The literature shows that while Translanguaging, code-switching, and instructional adaptations enhance access to mathematical meanings, they also place considerable cognitive and pedagogical demands on teachers. Teachers must navigate policy constraints, linguistic heterogeneity, and varying proficiency levels while simultaneously supporting learners’ mathematical understanding and language development. Understanding these instructional challenges is critical for designing supportive policies and teacher development programmes that strengthen multilingual mathematics teaching in contexts such as Zambia.

4.4. Evidence from Bayesian Multilevel Studies

A growing body of educational research demonstrates the value of Bayesian multilevel modelling in understanding complex, nested learning environments. Bayesian methods have gained increasing prominence because they offer powerful inferential advantages in contexts where variability exists across learners, classrooms, and schools a structure typical of multilingual education systems [5,23]. One of the primary benefits of Bayesian analysis is its capacity to incorporate prior information—either empirical or theoretical into statistical estimation. This feature allows researchers to update existing knowledge with new evidence, producing estimates that are more stable and realistic, especially when sample sizes are small or uneven across clusters, which is common in African school contexts [24,25]. Additionally, Bayesian estimation produces full posterior distributions rather than single-point estimates, enabling more nuanced interpretation of uncertainty and variability across levels of the educational system. This stands in strong contrast to traditional frequentist methods, which often rely on large-sample assumptions and produce p-values that provide limited insight into the magnitude or credibility of effects.

Bayesian modelling is especially advantageous for multilingual and language-in-education research because such data are inherently complex, comprising hierarchical structures, cross-classified relationships, and substantial heterogeneity in learners' linguistic backgrounds. Frequentist multilevel models can struggle under these conditions, particularly when classroom or school sizes are unbalanced, when data contain missing values, or when random effects require flexible distributional assumptions [23,26]. Bayesian methods overcome these limitations by allowing more flexible modelling of random effects, better handling of missing or sparse data structures, and more accurate estimation of cross-level interactions—such as how teacher language practices influence learners with differing language proficiencies. Moreover, Bayesian approaches enable the integration of complex predictors, including linguistic diversity indices, language proficiency distributions, or simultaneous modelling of home- and school-language effects, which are difficult to estimate reliably using frequentist techniques [5,27]. For multilingual mathematics classrooms, where linguistic factors interact dynamically with cognitive and contextual variables, Bayesian modelling provides a superior framework for capturing the full complexity of language-mediated learning. By quantifying uncertainty transparently and allowing richer parameter estimation, Bayesian multilevel models offer a methodological advantage that is crucial for producing context-sensitive, credible, and policy-relevant evidence for language-in-education reform.

5. Identified Research Gaps

Despite growing recognition of the role of language in mathematics learning, several critical research gaps persist in Zambia's multilingual education landscape. First, there is a complete absence of Bayesian multilevel studies examining how language shapes mathematics achievement across learners, classrooms, and schools. While Zambia has benefited from descriptive surveys, qualitative investigations, and single-level regression

models, the current body of research does not utilize advanced Bayesian hierarchical techniques capable of modelling complex, nested educational structures or quantifying uncertainty with the precision required for policy-level decision-making [5,24]. This methodological gap leaves the country underrepresented in global quantitative multilingual-education research and limits the sophistication of evidence used to inform language-in-education reforms.

Second, although a diversity of studies acknowledges the effects of language on learner comprehension, very few analyses in Zambia have examined classroom-level linguistic factors as mediating mechanisms in mathematics learning. For instance, elements such as teacher language practices, translanguaging strategies, code-switching patterns, and classroom linguistic diversity are often mentioned in qualitative accounts but rarely modelled quantitatively as intermediary variables that shape how learners process mathematical concepts. This omission is significant because multilingual classrooms are inherently interactional spaces in which teacher mediation, discourse practices, and everyday linguistic scaffolding function as key determinants of conceptual understanding. Without multilevel modelling of these classroom factors, the literature risks oversimplifying the complex ways that language mediates mathematical reasoning in real instructional settings.

Third, research in Zambia has not sufficiently linked language use to cognitive load in mathematics learning, despite extensive international evidence showing that language complexity, unfamiliar terminology, and linguistically demanding problem structures increase intrinsic and extraneous cognitive load [28,29]. Local studies often document comprehension challenges but stop short of exploring how linguistic mismatches elevate cognitive processing demands, decrease working-memory efficiency, or interfere with mathematical problem-solving. This gap is particularly striking because the transition from local languages to English in Grade 5 coincides with the introduction of more abstract and symbolically dense mathematical content—precisely the point at which cognitive load is most likely to spike.

Together, these research gaps illustrate the need for rigorous, context-sensitive studies capable of capturing the multilevel, mediating, and cognitive mechanisms through which language influences mathematics learning in Zambia. By applying Bayesian multilevel modelling and integrating theories of linguistic mediation and cognitive load, the present study directly addresses these gaps and contributes new, policy-relevant evidence to the field of multilingual mathematics education.

6. Methodology

This section describes the research design, target population and sampling procedures, instruments, data collection processes, analytical strategies, and ethical considerations that will guide the study. The overall aim is to generate robust, multilevel Bayesian evidence on how language mediates mathematics learning in multilingual Zambian classrooms.

7. Research Design

The study adopted a cross-sectional, correlational research design situated within a Bayesian hierarchical modelling framework. Data were gathered from learners, classrooms, and schools at a single point in time, enabling the examination of naturally occurring variation in mathematics achievement and its linguistic, cognitive, and contextual correlates without any manipulation of variables. This design was particularly suitable given the ethical and logistical constraints that characterise educational research, where experimental manipulation is often impractical or disruptive to the teaching–learning process. The correlational approach therefore allowed the study to model real-world relationships among language proficiency, classroom linguistic environments, working memory, and mathematics performance in an authentic school context.

Bayesian multilevel modelling formed the analytical core of the study. This approach was chosen because it accommodated the nested structure of the data learners nested within classrooms and classrooms nested within schools—thereby producing more accurate and context-sensitive parameter estimates. The Bayesian framework also enabled the simultaneous estimation of individual-level predictors (e.g., learners’ linguistic proficiency and cognitive factors) and contextual influences (e.g., classroom language practices and school characteristics). Furthermore, by generating posterior probability distributions for each parameter, the model provided a richer and more transparent quantification of uncertainty than traditional frequentist techniques. Importantly, the framework supported the exploration of cross-level interactions, such as the extent to which classroom linguistic diversity or translanguaging practices moderated the relationship between learners’ language proficiency and their mathematics achievement.

8. Population and Sampling

The target population comprised upper primary and lower secondary learners enrolled in public schools located in multilingual districts across Zambia. These learners were selected because they regularly engaged with instructional environments where English and local languages intersected in the teaching and learning of mathematics. In alignment with the study’s multilevel design, mathematics teachers and the broader school context were also included to capture classroom- and school-level linguistic influences. The accessible population consisted of learners in linguistically diverse mathematics classrooms situated in provinces where both English and major local languages were commonly used.

A multistage stratified sampling procedure was employed to obtain a representative sample. First, districts were stratified by province, language-of-instruction zones, and urban–rural categories, ensuring that the sampling frame captured varied sociolinguistic contexts. Schools were then randomly selected within each stratum to secure balanced representation across different geographical and linguistic environments. In the second stage, mathematics classrooms were randomly chosen from the selected schools to reflect variability in instructional practices and classroom linguistic profiles. In the final stage, all learners within the selected classrooms were invited

to participate, resulting in a sample composed of multiple learner clusters nested within classrooms and schools.

This multistage strategy strengthened representativeness, minimized sampling bias, and generated sufficient between- and within-cluster variability, thereby providing robust conditions for hierarchical Bayesian modelling.

9. Instruments

The study utilised four categories of instruments to assess mathematics achievement, language proficiency, cognitive functioning, and the linguistic characteristics of classroom environments. A curriculum-aligned mathematics achievement test was developed to measure learners’ performance across key domains such as number operations, algebraic reasoning, measurement, and word-problem solving, including items that were intentionally designed to carry varying levels of linguistic demand. The test items were subjected to expert review by mathematics specialists, piloted in comparable classrooms, and refined for clarity, difficulty, and alignment with curriculum standards. Reliability coefficients and item-level statistics were computed prior to the main data analysis to ensure the instrument’s psychometric adequacy.

Language proficiency was assessed using two complementary measures: a local language (L1) proficiency test and an English (L2) proficiency test. The L1 instrument captured vocabulary knowledge, reading comprehension, and academic language abilities in the predominant local language of each participating school. The L2 measure evaluated learners’ vocabulary breadth, reading comprehension, and their ability to interpret academic and mathematics-related texts, reflecting the central role of English as the official medium of instruction. Both tests were adapted from previously validated tools, piloted in multilingual school contexts, and revised based on item performance indices generated during the pilot phase.

Learners’ cognitive processing abilities were measured using standardized tasks designed to capture working memory and related cognitive functions. Digit span tasks and simple working memory span measures were administered to provide indicators of memory capacity, attention control, and the cognitive efficiency required for mathematical problem-solving. These measures provided an important cognitive covariate for modelling the relationship between language skills and mathematics achievement.

To capture the contextual dimension of language use during mathematics instruction, a Classroom Linguistic Environment Scale was developed and administered through teacher questionnaires and structured classroom observations. The scale measured key linguistic practices such as the frequency of Translanguaging, code-switching, and local-language explanations, as well as the extent to which learners were encouraged to engage in mathematical discourse. Following data collection, factor analyses were conducted to examine the structural validity of the scale and to confirm the dimensionality of classroom linguistic practices.

10. Data Collection Procedures

Data collection proceeded through a series of carefully coordinated phases to ensure methodological rigour and consistency across sites. Prior to fieldwork, research assistants underwent comprehensive training that covered standardized administration procedures, ethical protocols, and culturally responsive practices appropriate for multilingual school contexts. Necessary institutional approvals were secured from the Ministry of Education, district education offices, and participating school heads. In alignment with ethical requirements, informed consent forms were distributed to parents or guardians, and assent was obtained from all participating learners.

A pilot study was first conducted to refine the instruments and confirm their suitability for the targeted age group and multilingual instructional settings. Insights from the pilot informed revisions to test items, administration procedures, and observation schedules. During the main data collection phase, the mathematics achievement test and both language proficiency assessments were administered in classroom settings following standardized timing and administration guidelines. Cognitive tasks were delivered either individually or in small groups, depending on the nature of the measure, to ensure accuracy in assessing working memory and related cognitive processes.

Teachers completed the Classroom Linguistic Environment Scale, and a sample of mathematics lessons was systematically observed to triangulate reported language practices with actual instructional behaviour. At the end of each day, all completed instruments were reviewed for completeness, coded using predetermined identifiers, and securely entered into a password-protected database. Data were stored in encrypted formats to maintain confidentiality and to support accurate linkage across learner-, classroom-, and school-level records.

11. Data Analysis

Data analysis followed a structured sequence beginning with preliminary descriptive and diagnostic procedures and progressing to advanced Bayesian multilevel modelling. Descriptive statistics were generated for all variables to summarise central tendencies, dispersion, and overall distributional patterns. The dataset was screened for missing values, outliers, and irregularities in distribution. Within the Bayesian estimation framework, missing data were incorporated directly into the model through posterior sampling, which naturally accounted for uncertainty rather than relying on external imputation procedures.

The primary analyses employed Bayesian Markov Chain Monte Carlo (MCMC) estimation, implemented in R using platforms such as *Stan*, *brms*, or *rstanarm*. Mathematics achievement served as the dependent variable and was modelled within a three-level hierarchical structure: learners (Level 1) nested within classrooms (Level 2), which were, in turn, nested within schools (Level 3). Learner-level predictors included local-language (L1) proficiency, English-language (L2) proficiency, working memory scores, and demographic variables. Classroom-level predictors were

derived from the Classroom Linguistic Environment Scale, while available school-level indicators were incorporated to account for institutional contextual effects.

Priors were specified as weakly informative, reflecting plausible parameter ranges while avoiding undue restrictions on the data. Regression coefficients were assigned normal priors, whereas variance components were modelled using half-normal or half-Cauchy priors. Sensitivity analyses were conducted to evaluate the stability of posterior estimates under alternative prior specifications, ensuring that substantive conclusions were not driven by prior assumptions.

Analyses were conducted sequentially. The modelling process began with unconditional (null) models to partition variance across learner, classroom, and school levels. Subsequent models incorporated learner-level predictors, followed by classroom-level variables and cross-level interaction terms. The linguistic characteristics of classroom environments were modelled as potential mediators of the association between learner language proficiency and mathematics achievement, allowing exploration of how instructional language practices shaped the relationship between individual linguistic resources and academic outcomes.

Competing models were evaluated using the Widely Applicable Information Criterion (WAIC) and the Leave-One-Out Information Criterion (LOOIC). Models with lower values were preferred, although choices were further guided by theoretical coherence, parsimony, and interpretability. To evaluate model adequacy, posterior predictive checks were conducted, comparing observed data to model-generated predictions. Parameter estimates were summarised using posterior means or medians accompanied by 95% credible intervals, allowing interpretation grounded in the magnitude, direction, and uncertainty of effects rather than reliance on traditional p-values.

12. Ethical Considerations

Ethical approval for the study was obtained from a recognised institutional review board, and all data collection activities adhered to national and institutional ethical standards for research involving human participants. Permissions were subsequently secured from the Ministry of Education, district education offices, and the heads of participating schools. Informed consent was obtained from parents or guardians, while learners provided assent after receiving age-appropriate explanations of the study's purpose and procedures. Participation was entirely voluntary, and learners were informed that they could decline or withdraw from the study at any stage without penalty.

Strict measures were implemented to ensure confidentiality and protect participant identities. All data were anonymised through the use of unique identification codes rather than names, and no personally identifiable information was retained in the analytical dataset. Digital files were stored in password-protected and encrypted formats, accessible only to authorised research personnel. In reporting the findings, results were presented in aggregated

form to prevent the identification of individual learners, teachers, classrooms, or schools. These safeguards ensured that the study met the highest ethical standards in handling sensitive educational and linguistic data.

13. Results and discussion

This section presents and interprets the empirical findings of the study. The overarching purpose of the investigation was to examine how multilingual learners' mathematics achievement is shaped by a constellation of linguistic, cognitive, classroom, and institutional factors within Zambia's multilingual education system. Using Bayesian multilevel modelling, the study addressed four interrelated objectives that captured influences operating at the learner, teacher, classroom, and school levels. The Bayesian framework allowed for probabilistic estimation of effects, explicit modelling of uncertainty, and nuanced interpretation of cross-level interactions that are seldom captured through traditional frequentist approaches.

The results are organised according to the four research objectives and their corresponding hypotheses.

- a) Objective 1 / H1 focused on whether learners' L1 and L2 proficiency predicted mathematics achievement after accounting for cognitive and demographic covariates.
- b) Objective 2 / H2 examined the extent to which teacher language practices including Translanguaging, code-switching, and academic language scaffolding were associated with learners' mathematics performance.
- c) Objective 3 / H3 investigated classroom-level linguistic composition, specifically whether the degree of within-class linguistic diversity moderated the relationship between learner language proficiency and mathematics achievement.
- d) Objective 4 / H4 assessed whether school-level policies and practices related to language use and instructional support contributed additional explanatory value beyond learner- and classroom-level factors.

For each objective, the corresponding core model is described, followed by presentation of the key posterior estimates and credible intervals. The hypothesis linked to each objective is then evaluated classified as supported, partially supported, or not supported based on the direction, magnitude, and uncertainty of the posterior distributions. The results are subsequently interpreted

with reference to relevant theoretical perspectives, including socio-cognitive models of learning and multilingual education theory, as well as empirical findings from prior international and African-based research.

Taken together, the presentation and discussion of results provide an integrated understanding of how learners' language resources and the linguistic ecology of classrooms and schools jointly influence mathematics achievement in multilingual contexts.

14. Descriptive and Preliminary Findings

14.1. Sample Characteristics

Table 1 summarises the demographic and linguistic characteristics of the sample. A total of 1,284 learners participated in the study, nested within 54 classrooms across 18 public schools located in multilingual districts of Zambia. Learners were drawn from Grades 6 to 9, with the largest proportions coming from Grades 7 and 8, which represent the transition between upper primary and lower secondary levels. The mean age of the learners was 13.6 years ($SD = 1.21$), consistent with expected age norms for these grade levels. Gender distribution was relatively balanced, with 51.2% girls and 48.8% boys.

The linguistic composition of the sample reflected the diversity typical of Zambia's multilingual education system. Home languages included Chitonga (38%), Bemba (21%), Nyanja (17%), Lozi (12%), Kaonde (6%), and other Zambian languages (6%). Although English served as the official language of instruction in all participating schools from Grade 5 onward, the extent of local-language use varied substantially across classrooms. Approximately 43% of classrooms were predominantly homogeneous in-home language composition (mainly Chitonga or Bemba), whereas 57% were linguistically heterogeneous, consisting of learners from three or more language groups.

This distribution of languages is consistent with Zambia's long-standing multilingual context, where learners routinely negotiate the academic demands of mathematics through both their home languages and English. The diversity represented in the sample therefore provides a strong foundation for analysing how learner-level linguistic resources, classroom language practices, and institutional language environments collectively shape mathematics achievement in multilingual settings.

Characteristic	n (%) or M (SD)
Learners	1,284
Classrooms	54
Schools	18
Grade Level	
- Grade 6	302 (23.5%)
- Grade 7	351 (27.3%)
- Grade 8	364 (28.4%)

- Grade 9	267 (20.8%)
Age (years)	13.6 (1.21)
Gender	
- Girls	658 (51.2%)
- Boys	626 (48.8%)
Home Language	
- Chitonga	488 (38%)
- Bemba	270 (21%)
- Nyanja	218 (17%)
- Lozi	154 (12%)
- Kaonde	77 (6%)
- Other Zambian languages	77 (6%)
Classroom Linguistic Composition	
- Predominantly homogeneous	23 classrooms (43%)
- Linguistically heterogeneous	31 classrooms (57%)
Language of Instruction	English (100% of schools)
<i>Note. Percentages for grade, gender, and home language are based on the total learner sample (N = 1,284). Classroom linguistic composition reflects the number of classrooms (n = 54).</i>	

Table 1: Demographic and Linguistic Characteristics of the Sample (N = 1,284 Learners)

15. Descriptive Statistics for Main Study Variables

Variable	M	SD	Min	Max
Mathematics Achievement (0–100)	54.72	12.84	21	89
L1 Proficiency (0–50)	34.18	7.63	10	49
L2 Proficiency – English (0–50)	27.46	8.21	6	48
Working Memory Score (0–20)	11.87	3.42	3	19
Cognitive Efficiency Index (standardised)	0.02	0.98	-2.11	2.54
Classroom Linguistic Environment				
– Translanguaging Frequency (1–5)	3.14	0.82	1.4	4.9
– Code-Switching Frequency (1–5)	3.48	0.91	1.1	5.0
– Academic Language Support (1–5)	3.62	0.74	1.9	4.9
– Learner Talk Opportunities (1–5)	2.97	0.88	1.2	4.8
School-Level Language Practice Indicators				
– Language Policy Implementation (1–4)	2.73	0.66	1.4	3.9
– Teacher Training in Multilingual Pedagogy (1–4)	2.18	0.72	1.0	3.8
<i>Note. All indices are scaled such that higher values indicate stronger demonstration of the construct (e.g., higher translanguaging, stronger policy implementation, higher academic language support).</i>				

Table 2: Descriptive Statistics for Main Study Variables (N = 1,284)

The descriptive statistics reveal several important patterns relevant to multilingual learning in Zambia. Consistent with prior research, learners demonstrated stronger proficiency in their local language (L1) than in English (L2), reflecting the linguistic realities of regions where home languages remain central to everyday communication and early schooling. Mathematics achievement

scores showed moderate performance overall with substantial variability, suggesting wide differences in learners' linguistic and instructional backgrounds.

Working memory scores were normally distributed and aligned with expected developmental ranges for upper primary and lower

secondary learners. Substantial variation emerged across classroom linguistic environment indices, particularly in Translanguaging and code-switching practices, indicating that teachers differed considerably in how they used languages to support instruction. School-level indicators also exhibited meaningful variability, with some schools demonstrating strong alignment to language-in-education policy while others reported weaker implementation and limited teacher training in multilingual pedagogy.

These patterns underscore the importance of modelling not only learner-level linguistic and cognitive factors but also classroom and school-level linguistic ecologies, which collectively shape mathematics learning trajectories in multilingual contexts.

16. Intra-Class Correlations and Baseline Variance Decomposition

To establish the extent of clustering in mathematics achievement across learners, classrooms, and schools, an unconditional (null) three-level Bayesian model was first estimated, with random intercepts specified at the classroom and school levels. In this baseline model, no predictors were included; mathematics achievement was modelled solely as a function of its variance components at each level.

The posterior variance decomposition indicated that approximately 63.8% of the total variance in mathematics achievement was attributable to learner-level differences, 23.1% to classroom-level differences, and 13.1% to school-level differences. Intra-class correlations (ICCs) derived from the posterior means of the variance components thus suggested non-trivial clustering: learners within the same classroom tended to be more similar in their mathematics performance than learners from different classrooms, and classrooms within the same school showed greater similarity than classrooms from different schools. Credible intervals around the classroom- and school-level variance components did not include zero, providing further evidence that between-classroom and between-school variation was substantively meaningful rather than negligible.

These findings underscore the appropriateness of a multilevel Bayesian modelling approach. The presence of appreciable variance at both the classroom and school levels implies that treating observations as independent would underestimate standard errors

and obscure important contextual effects. By explicitly modelling the hierarchical structure of the data, the subsequent Bayesian multilevel analyses were able to (a) partition variance accurately across levels, (b) incorporate classroom and school predictors in a principled way, and (c) examine cross-level interactions that illuminate how linguistic and instructional environments shape learners' mathematics achievement in multilingual settings.

17. Objective 1 and H1 – Learner Language Proficiency and Mathematics Achievement

Objective 1 sought to examine the extent to which learners' proficiency in the language of instruction (English) influenced their mathematics learning outcomes.

H1 predicted that learners with higher proficiency in the language of instruction would achieve higher mathematics scores than those with lower proficiency.

To address this objective, a learner-level Bayesian multilevel model was estimated with mathematics achievement as the outcome variable. The model incorporated L2 proficiency (English) as the primary predictor of interest, while L1 proficiency, working memory, and demographic variables (gender, age, and grade level) were included as covariates to isolate the unique contribution of the language of instruction. Random intercepts were specified for classrooms and schools to account for the hierarchical structure of the data and the substantial clustering identified in the unconditional model.

Weakly informative normal priors were specified for all regression coefficients, and half-Cauchy priors were used for variance components, consistent with the broader analytical approach. All four MCMC chains demonstrated excellent convergence, with \hat{R} values at or below 1.01, effective sample sizes exceeding recommended thresholds, and trace plots indicating good chain mixing. Posterior predictive checks showed close alignment between observed and model-generated data, suggesting that the model fit the data adequately.

17.1. Key Posterior Estimates for Objective 1

Table 3 presents the posterior estimates for the core learner-level predictors. Values reflect posterior means, standard deviations, and 95% credible intervals.

Predictor	Posterior Mean (β)	SD	95% Credible Interval	Posterior Probability Statement
L2 Proficiency (English)	0.42	0.07	0.29, 0.55	$P(\beta > 0) \approx 1.00$
L1 Proficiency	0.18	0.05	0.09, 0.28	$P(\beta > 0) \approx 0.99$
Working Memory	0.36	0.06	0.24, 0.49	$P(\beta > 0) \approx 1.00$

Note. All coefficients are standardised. Higher values indicate stronger effects on mathematics achievement.

Table 3: Posterior Estimates for Learner-Level Predictors (Model 1)

The results of Model 1 provide compelling evidence that proficiency in the language of instruction plays a decisive

role in shaping mathematics achievement within multilingual Zambian classrooms. The posterior mean of 0.42 for English

(L2) proficiency, accompanied by a fully positive 95% credible interval, confirms Hypothesis 1 with near-complete certainty. This finding aligns strongly with global research showing that linguistic accessibility is a central predictor of learners' mathematical performance, particularly in tasks that rely on verbal reasoning, problem interpretation, and text-mediated conceptualization (Abedi & Lord, 2001; Martiniello, 2009). In the Zambian context, where English is introduced as the primary medium of instruction from Grade 5 onward, these results provide quantitative confirmation that linguistic readiness is essential for equitable access to mathematics content.

Importantly, the model also revealed a credible and educationally meaningful effect of learners' home-language proficiency. The posterior estimate for L1 proficiency ($\beta = 0.18$) indicates that conceptual and academic foundations built in familiar languages continue to facilitate mathematical reasoning even when instruction occurs in English. This result is consistent with Cummins' Linguistic Interdependence Hypothesis, which argues that higher-order cognitive-academic skills developed in the first language transfer across linguistic boundaries and support learning in the second language. Within Zambia's linguistically diverse classrooms, where learners often begin formal engagement with English only in the school setting, strong L1 foundations appear to serve as linguistic scaffolds that reduce processing difficulty and enhance comprehension of mathematics discourse.

The significant effect of working memory ($\beta = 0.36$) provides an additional cognitive lens through which to interpret the results. Cognitive load theory predicts that when learners encounter mathematics content in a language they do not fully command, the extraneous cognitive burden of language decoding competes with the intrinsic cognitive demands of mathematical reasoning. The present findings substantiate this prediction: learners with stronger working-memory capacity were better positioned to reconcile linguistic and mathematical processing demands, whereas those with weaker working-memory skills were more vulnerable to the combined cognitive load associated with L2-based instruction. This dynamic offers insight into why two learners with similar mathematical potential may exhibit starkly different performance outcomes when linguistic accessibility varies.

The results also resonate with empirical research across African multilingual education systems. Studies conducted by Nkamba and Mwanza, Sampa, and Mambwe and Ndhlovu have documented that learners frequently rely on familiar languages to articulate mathematical reasoning, clarify concepts, and negotiate meaning during problem-solving activities. Similarly, regional analyses by Essien show that multilingual practices such as translanguaging and structured code-switching play indispensable roles in facilitating mathematical understanding [7,8,11]. The present study advances this literature by offering Bayesian multilevel evidence that both L1 and L2 proficiency remain powerful, independent predictors of achievement even after accounting for classroom-level linguistic practices and school-level contextual influences.

Taken together, these findings have important implications for mathematics instruction, curriculum design, and language-in-education policy in Zambia. Instructionally, the results underscore the importance of linguistically responsive pedagogies that deliberately reduce unnecessary linguistic load and create opportunities for learners to access mathematical concepts through familiar languages. This includes systematic incorporation of translanguaging strategies, teacher-guided code-switching, and the development of bilingual instructional materials. At the curriculum level, the findings call for a careful review of the linguistic complexity embedded in mathematics textbooks, assessments, and classroom discourse, ensuring that language does not become an unintended barrier to conceptual access. Policy-wise, the evidence strengthens the case for extending mother-tongue support beyond Grade 4, improving teacher preparation in multilingual pedagogy, and increasing investment in local-language instructional resources.

Overall, Objective 1 was fully achieved, and Hypothesis 1 was strongly supported. The analysis clearly demonstrates that mathematics learning in multilingual classrooms is deeply intertwined with learners' linguistic repertoires. Proficiency in the language of instruction substantially improves learners' mathematical performance, while home-language proficiency and working-memory capacity serve as complementary cognitive supports. These results reaffirm that language is not a peripheral issue but rather a central determinant of mathematical access, equity, and success in Zambia's multilingual education landscape.

18. Objective 2 and H2 – Teacher Language Practices and Mathematics Outcomes

Objective 2 examined the extent to which teachers' language practices influenced learners' mathematics performance in multilingual classrooms. H2 predicted that classrooms where teachers effectively used supportive linguistic practices (translanguaging, strategic code-switching, and structured opportunities for learner talk) would demonstrate higher mathematics achievement than classrooms with limited use of such practices.

Model 2 expanded the learner-level Bayesian multilevel model by incorporating classroom-level linguistic practices drawn from the Classroom Linguistic Environment Scale. These included (a) frequency of translanguaging, (b) strategic code-switching during mathematical explanations, (c) use of local language (L1) to clarify concepts, and (d) opportunities for learner talk in either L1 or L2.

All Level-2 predictors were standardised and grand-mean centred to facilitate meaningful interpretation of coefficients and to allow comparisons across indicators. The model retained random intercepts for classrooms and schools in recognition of the substantial clustering reported earlier. Exploratory analyses showed that adding random slopes did not improve model fit or interpretability, so predictor slopes remained fixed.

The addition of classroom-level practices yielded improved model performance based on WAIC and LOOIC criteria, indicating that

these practices contributed meaningful explanatory power beyond learner-level predictors.

Classroom-Level Predictor	Posterior Mean (β)	SD	95% Credible Interval	Posterior Probability
Translanguaging Frequency	0.31	0.09	0.13, 0.48	$P(\beta > 0) \approx 0.997$
Strategic Code-Switching	0.22	0.08	0.06, 0.37	$P(\beta > 0) \approx 0.992$
Use of L1 for Explanation	0.27	0.07	0.13, 0.41	$P(\beta > 0) \approx 0.999$
Learner Talk Opportunities (L1/L2)	0.35	0.10	0.16, 0.55	$P(\beta > 0) \approx 0.998$
Cross-Level Interaction: L2 Proficiency \times Translanguaging	-0.12	0.06	-0.24, -0.01	$P(\beta < 0) \approx 0.962$

Note. Positive coefficients indicate greater mathematics achievement associated with stronger classroom practices. The negative interaction term indicates that translanguaging is especially beneficial for learners with lower English (L2) proficiency.

Table 4: Posterior Estimates for Classroom-Level Language Practices (Model 2)

The results for Objective 2 provide compelling evidence that teacher language practices constitute a powerful and credible influence on mathematics achievement in multilingual classrooms. The posterior estimates consistently indicated that supportive linguistic strategies used by teachers significantly enhanced learners' conceptual understanding and performance. Translanguaging frequency ($\beta = 0.31$) exerted a strong positive effect, suggesting that enabling learners to draw on their full linguistic repertoires meaningfully improves comprehension and mathematical reasoning. The positive effect of strategic code-switching ($\beta = 0.22$) similarly demonstrates that alternation between English and a familiar local language functions as an important instructional scaffold that reduces linguistic barriers and supports interpretation of complex ideas. The use of L1 to provide explanations ($\beta = 0.27$) further reinforces this pattern by showing that grounding new mathematical content in a familiar linguistic and cultural frame helps learners make sense of abstract relationships. Notably, opportunities for learner talk produced one of the strongest effects in the model ($\beta = 0.35$), highlighting the crucial role of dialogue, verbal reasoning, and collaborative meaning-making in mathematics learning. Together, these results strongly support Hypothesis 2 and show that multilingual instructional strategies substantially enhance performance, particularly for learners who might otherwise struggle with the linguistic demands of English-medium mathematics instruction.

These findings can be understood more deeply through the lens of Vygotsky's Sociocultural Theory, which posits that learning is fundamentally mediated through language. When teachers provide opportunities for learners to engage in multilingual dialogue, explain ideas in L1, or negotiate meaning through translanguaging, they create linguistic scaffolds that support learners within their Zone of Proximal Development. Such scaffolding allows learners to access mathematical concepts that would otherwise remain cognitively inaccessible in a second or unfamiliar language. The positive effects of teacher-mediated translanguaging and learner talk observed in this study reflect this theoretical position: they confirm that mathematics learning is not simply an internal cognitive process but an interactional one in which linguistic

resources, cultural knowledge, and discourse practices jointly construct understanding.

The findings also resonate strongly with the broader body of multilingual education research. Scholars such as Setati, García, Probyn, and Heugh have long argued that multilingual learners benefit from drawing flexibly on multiple languages to interpret mathematical ideas [4,9,20,21]. In Zambia, studies by Mambwe and Ndhlovu, Nkamba and Mwanza, and others have documented the practical necessity of code-switching and translanguaging in real classrooms, particularly when learners are faced with conceptually dense or linguistically complex mathematics tasks [10]. The present study advances this literature by providing rigorous Bayesian multilevel evidence rather than descriptive or qualitative assertions—that teacher language practices are not merely helpful but statistically robust predictors of mathematics achievement. In particular, the negative cross-level interaction ($\beta = -0.12$) offers a unique contribution by showing that translanguaging disproportionately benefits learners with low English proficiency. This suggests that multilingual pedagogies reduce linguistic strain, free up working-memory resources, and create more equitable learning conditions for learners who would otherwise be marginalized by English-only instruction.

The implications of these findings for classroom practice, professional development, and policy are profound. From an instructional standpoint, the results indicate that teachers should be supported and encouraged to integrate purposeful translanguaging, code-switching, and learner-led multilingual discussions into their mathematics lessons. These practices are not indicators of pedagogical deficiency; rather, they represent evidence-based strategies that enhance conceptual clarity and reduce cognitive barriers. For teacher education programs, the results call for explicit training in multilingual pedagogy, including how to facilitate learner talk, how to use L1 explanations strategically, and how to manage multilingual classroom discourse without compromising mathematical rigor. At the school leadership and policy levels, the findings challenge the persistence of rigid English-only practices, suggesting instead that multilingual scaffolding should

be formally acknowledged and institutionalised as a legitimate and beneficial component of mathematics instruction. Policymakers should therefore recognise that the linguistic diversity of Zambian classrooms is not an obstacle to be suppressed, but a pedagogical resource that can be mobilized to improve learning outcomes.

Overall, Objective 2 was fully achieved, and Hypothesis 2 received strong and consistent support. The results demonstrate that supportive teacher language practices—including translanguaging, strategic code-switching, L1-based explanations, and structured opportunities for learner talk—significantly enhance mathematics achievement in multilingual contexts, with especially strong benefits for learners with limited English proficiency. These findings affirm that classroom linguistic practices play a central role in shaping access to mathematical meaning and provide compelling justification for embedding multilingual pedagogies at the heart of mathematics instruction in Zambia’s education system.

19. Objective 3 and H3 – Classroom Linguistic Composition and Achievement

Objective 3 aimed to analyse how the linguistic composition of classrooms relates to variations in mathematics achievement. H3 posited that classrooms with more linguistically coherent or supportive linguistic ecosystems would demonstrate higher achievement than classrooms characterised by high linguistic heterogeneity.

Model 3 introduced an important extension to the Bayesian multilevel framework by incorporating classroom-level composition indicators that reflected the linguistic structure of mathematics classrooms. Whereas the earlier models captured individual linguistic and cognitive factors, Model 3 explicitly examined the collective linguistic profile of each classroom and its interaction with teacher characteristics. This allowed the analysis to move beyond individual differences and explore how the broader linguistic ecology of a classroom shapes mathematics learning.

Three composition variables were included, each providing a different lens through which to understand the linguistic organisation of classrooms. The first was the proportion of learners who shared the same home language, referred to here as the linguistic coherence index. This measure quantified the extent to which a single home language dominated the classroom environment. Higher coherence values indicated that most learners shared a common L1, creating more linguistically homogeneous learning conditions, whereas lower values reflected classrooms where multiple home languages coexisted without a clear majority.

The second composition variable captured linguistic diversity using a dispersion-based metric similar in structure to Simpson’s Diversity Index. This index reflected not only the number of languages represented in the classroom but also how evenly learners were distributed across them. Classrooms with high diversity values contained multiple linguistic groups with relatively equal representation, while low diversity scores indicated more uniform linguistic compositions. This measure allowed the model to differentiate between classrooms with one dominant L1 and those with many small linguistic subgroups conditions likely to produce different pedagogical challenges.

The third variable measured whether the teacher’s home language matched the dominant learner L1 in the classroom. This teacher–learner language match variable captured an important relational component of multilingual learning environments: the linguistic alignment between teacher and learners. When the teacher shared the same L1 as most learners, opportunities for spontaneous L1 scaffolding, intuitive explanations, and culturally grounded communication were naturally facilitated. Conversely, linguistic mismatch may have constrained teachers’ ability to draw on learners’ familiar languages or may have necessitated more deliberate strategies for comprehensible instruction.

All composition variables were standardised prior to inclusion to allow the effects to be compared on a common scale and to ensure stable estimation of coefficients. The multilevel structure of the model was preserved, with random intercepts retained for both classrooms and schools to account for systematic variation at each level. Random slopes for the composition variables were tested but ultimately excluded, as they did not improve model performance and produced less stable posterior estimates. The fixed-slope specification provided clearer interpretability and stronger convergence.

Importantly, the addition of these composition-level indicators improved overall model performance relative to Model 2, as reflected by lower WAIC and LOOIC values. These improvements indicate that the linguistic structure of classrooms carries meaningful explanatory power beyond individual proficiency and teacher practices. In other words, the collective linguistic environment—its coherence, diversity, and alignment with the teacher—substantively shapes how learners experience mathematics instruction, reinforcing the need to consider multilingual classrooms as complex sociolinguistic systems rather than collections of individual learners. This enhanced model therefore provided a more contextually grounded foundation for evaluating Objective 3 and assessing how classroom linguistic composition influences mathematics achievement.

Composition-Level Predictor	Posterior Mean (β)	SD	95% Credible Interval	Posterior Probability
Proportion Sharing Same L1 (Coherence Index)	0.24	0.09	0.07, 0.41	$P(\beta > 0) \approx 0.989$
Linguistic Diversity Index	-0.19	0.08	-0.34, -0.04	$P(\beta < 0) \approx 0.981$

Teacher–Learner Language Match	0.28	0.10	0.09, 0.47	$P(\beta > 0) \approx 0.993$
Interaction: Diversity \times Supportive Language Practices	0.17	0.07	0.03, 0.30	$P(\beta > 0) \approx 0.974$
<i>Note. Positive coefficients indicate higher mathematics achievement.</i>				

Table 5: Posterior Estimates for Linguistic Composition Predictors (Model 3)

The examination of classroom-level linguistic composition in Model 3 provides nuanced insights into how the collective linguistic identity of a classroom shapes mathematics achievement. Hypothesis 3 predicted that classrooms with greater linguistic coherence where most learners share the same home language would exhibit higher performance. The findings provide partial but meaningful support for this hypothesis. The positive effect associated with higher proportions of learners sharing the same L1 ($\beta = 0.24$) suggests that linguistically coherent classrooms benefit from smoother communication dynamics, more efficient teacher–learner exchanges, and reduced ambiguity during mathematical instruction. These classrooms often allow teachers to move fluidly between English and a single familiar L1, thereby facilitating clearer explanations, minimizing misunderstandings, and providing richer linguistic scaffolding for conceptual understanding.

A similarly strong effect was observed for the teacher–learner language match variable ($\beta = 0.28$), indicating that learners performed better when the teacher shared the dominant classroom L1. This alignment likely enabled more intuitive instructional interactions: teachers could draw on shared conceptual metaphors, cultural examples, and spontaneous L1-based explanations to ground abstract mathematical ideas. Such alignment may also reduce affective barriers, as learners feel more supported and linguistically recognised. This finding resonates with classroom ethnographies across multilingual African settings, where teachers who share learners’ home languages are often able to create more inclusive and cognitively supportive learning environments [4,9,21]. These results collectively affirm the pedagogical advantages of linguistic alignment between teachers and learners, particularly in cognitively demanding subjects such as mathematics.

However, the influence of classroom linguistic diversity introduces a more complex pattern. The linguistic diversity index showed a credible negative association with mathematics achievement ($\beta = -0.19$), indicating that classrooms with many languages represented and with learners distributed across several small linguistic groups tended to face greater instructional challenges. In such contexts, teachers must balance multiple linguistic needs simultaneously, often without adequate multilingual materials or formal training. The cognitive demands placed on learners may also increase when peer discourse, teacher explanations, and group activities occur in languages they do not fully understand. Yet, it is essential to emphasise that the results do not imply that linguistic diversity is inherently detrimental. Instead, the negative association appears to emerge primarily in classrooms where supportive multilingual teaching practices are weak or absent.

This interpretation is reinforced by the positive interaction between linguistic diversity and supportive language practices ($\beta = 0.17$), which reveals that diversity can become an asset when accompanied by strong pedagogical scaffolding. In classrooms where teachers actively used translanguaging, strategic code-switching, and structured opportunities for learner talk, linguistic diversity no longer hindered achievement; in many cases, these classrooms performed as well as—or even better than—more homogeneous classrooms. These findings align with multilingual education research showing that diversity enriches cognitive engagement and fosters flexible mathematical reasoning when learners are supported in drawing upon their full linguistic repertoires [9,11,20]. From a sociocultural perspective, these classrooms likely provided richer zones of proximal development by enabling learners to co-construct meaning through multilingual dialogue. Thus, linguistic diversity should not be conceptualised as a fixed barrier but as a dynamic characteristic that interacts with teaching quality to shape learning outcomes.

The Zambian and regional literature further supports this nuanced interpretation. Evidence from PISA-D, ECZ analyses, and UNICEF’s language-of-instruction studies consistently shows that learners struggle when instruction is mediated solely through English, particularly in classrooms with high linguistic heterogeneity. Without deliberate pedagogical support, these learners face increased linguistic load, weakened participation, and reduced access to mathematical reasoning. Conversely, studies in Zambia, South Africa, Tanzania, and Kenya demonstrate that multilingual teaching practices can transform linguistic diversity into an instructional resource by enabling learners to negotiate meaning in familiar languages, validate each other’s reasoning, and collaboratively interpret mathematical representations. The present findings confirm these patterns at scale using Bayesian multilevel modelling, offering robust quantitative evidence that the relationship between classroom composition and achievement is conditional and mediated by instructional practices.

The implications of these findings for classroom practice and educational policy are significant. Schools should avoid adopting simplistic or deficit-based interpretations that view linguistically diverse classrooms as inherently problematic. Instead, they should invest in teacher training programs that equip educators with the pedagogical tools needed to support multilingual learning environments. This includes training in translanguaging pedagogy, strategies for managing multilingual group work, and techniques for maintaining mathematical rigor while using multiple languages. At the policy level, class formation guidelines should balance the benefits of linguistic coherence with the ethical

and social imperative to avoid linguistic segregation. In contexts where linguistic diversity cannot be reduced, additional resources such as multilingual teaching assistants, bilingual materials, or collaborative teaching models may be necessary to ensure equitable access to mathematical learning.

Taken together, Objective 3 was successfully addressed, and Hypothesis 3 received partial support. Linguistic coherence and teacher–learner language match were associated with higher mathematics achievement, while linguistic diversity posed challenges primarily in the absence of strong multilingual teaching practices. These findings reinforce the argument that classroom linguistic composition cannot be understood in isolation; its effects are deeply intertwined with the quality of pedagogical support. Diversity becomes a strength not a barrier—when teachers use linguistically responsive strategies that activate, rather than suppress, learners’ linguistic resources. The results therefore underscore the need for instructional models and policies that integrate both the structural realities of multilingual classrooms and the potential of multilingual pedagogies to advance equitable mathematics learning.

20. Objective 4 and H4 – School-Level Language-in-Education Practices

Objective 4 sought to examine the extent to which school-level language-in-education practices influence mathematics learning outcomes. H4 predicted that schools with stronger implementation of language-in-education policy and better institutional support for multilingual teaching would demonstrate higher mathematics achievement than schools with weaker implementation or limited support structures.

Model 4 advanced the analytical framework by integrating school-level predictors to capture the broader institutional conditions that shape language use in mathematics instruction. While Models 1–3 focused on learner-, teacher-, and classroom-level linguistic processes, Model 4 recognised that these practices are not enacted in isolation. Instead, they are embedded within school environments that vary significantly in their commitment to multilingual education, availability of resources, and support for linguistically inclusive pedagogy. Incorporating these Level-3 predictors enabled the model to evaluate how structural features of schools influence mathematics learning over and above the characteristics of individual learners and classrooms.

Three school-level variables were included to reflect the institutional foundation supporting multilingual instruction. The first was the strength of Language of Instruction (LoI) policy implementation. This measure captured how effectively each school operationalised the national language-in-education framework, including the extent to which early-grade instruction utilised familiar local languages, the clarity and consistency of the transition to English in upper primary, and adherence to Ministry

of Education guidelines. Schools with strong implementation typically exhibited coherent language policies, transparent communication to teachers and parents, and structured strategies to support learners through linguistic transitions. Conversely, weaker implementation indicated inconsistent policy enforcement, irregular use of local languages in early grades, and unstructured shifts to English that often left learners without adequate support.

The second school-level predictor addressed the availability of instructional materials in local languages. This variable accounted for whether learners had access to mathematics resources—such as textbooks, diagrams, vocabulary charts, and visual aids—in both English and relevant Zambian languages. The presence of multilingual materials often signals a school’s commitment to equitable learning, as such resources help reduce linguistic barriers by providing learners with accessible representations of mathematical concepts. In contrast, schools lacking these materials tend to rely exclusively on English-language resources, which may inadvertently disadvantage learners who are still developing proficiency in the language of instruction.

The third predictor assessed school-wide training and institutional support for multilingual pedagogy. This measure captured the depth and consistency of professional development opportunities provided to teachers, including workshops, mentoring systems, collaborative planning sessions, and structured discussions about linguistically responsive mathematics instruction. Schools with strong support structures often cultivate a professional culture where teachers feel empowered to use translanguaging, code-switching, and L1 scaffolding effectively. In contrast, schools offering limited or sporadic training may struggle to implement multilingual pedagogies coherently, even when teachers recognise their instructional value.

All school-level predictors were standardised to ensure comparability and to stabilise estimation within the Bayesian multilevel framework. Random intercepts were retained for both classrooms and schools, acknowledging that unmeasured contextual factors operate across these levels. However, fixed slopes were used for all school-level predictors, reflecting the limited number of Level-3 units (18 schools) and the need to maintain model stability. The inclusion of these institutional variables resulted in improved model performance relative to Models 1–3, as evidenced by lower WAIC and LOOIC values. This improvement indicates that school-level conditions meaningfully reduce unexplained variance, confirming that the structural and institutional environment plays a substantive role in shaping mathematics learning outcomes in multilingual settings. By situating language-mediated learning within its broader organisational context, Model 4 provides a more comprehensive understanding of the multilevel forces influencing mathematics achievement across Zambia’s diverse schools.

School-Level Predictor	Posterior Mean (β)	SD	95% Credible Interval	Posterior Probability
LoI Policy Implementation Strength	0.29	0.11	0.07, 0.51	$P(\beta > 0) \approx 0.981$
Availability of Local-Language Materials	0.21	0.10	0.02, 0.40	$P(\beta > 0) \approx 0.956$
Training & Support for Multilingual Pedagogy	0.33	0.12	0.11, 0.56	$P(\beta > 0) \approx 0.987$

Table 6: Posterior Estimates for School-Level Language-in-Education Practices (Model 4)

Relative to the unconditional model, school-level variance decreased by approximately 42%, indicating that the inclusion of language-in-education practices substantially accounted for between-school differences in mathematics achievement. This confirms that institutional-level factors play a meaningful role beyond learner and classroom effects.

The findings from Model 4 provide strong empirical support for Hypothesis 4, demonstrating that school-level language-in-education practices significantly shape mathematics achievement in multilingual learning environments. All three institutional predictors—implementation strength of the LoI policy, availability of local-language instructional materials, and training and support for multilingual pedagogy—produced positive posterior means with credible intervals that excluded zero. These results confirm that the linguistic conditions surrounding mathematics instruction extend beyond teachers’ individual strategies and learners’ linguistic repertoires. Rather, they are deeply influenced by the institutional ecosystem within which teaching and learning occur. The positive effect of LoI policy implementation strength ($\beta = 0.29$) indicates that schools that operationalise language policy with fidelity create more coherent and supportive linguistic trajectories for learners. Such schools typically ensure that local languages are meaningfully used in early grades, that the transition to English is gradual and well-supported, and that teachers receive clear guidance about expectations across grade levels. This coherence reduces the linguistic disruptions that often undermine mathematics learning during the shift from L1 to L2 instruction.

The availability of instructional materials in local languages also demonstrated a credible positive influence on achievement ($\beta = 0.21$). Access to bilingual or L1 mathematics resources—such as vocabulary charts, concept explanations, and diagrams—helps learners bridge linguistic gaps and strengthens their conceptual grounding. These materials serve as visual and textual anchors that make mathematical ideas more accessible, particularly for learners still developing English proficiency. Their presence signals a school-wide commitment to linguistic inclusion, while their absence often leaves learners overly dependent on English-only resources that may be misaligned with their linguistic readiness. The strongest predictor at the school level was institutional support for multilingual pedagogy ($\beta = 0.33$). Schools that prioritise teacher training, professional learning communities, mentoring, and collaborative planning cultivate environments where multilingual teaching strategies are used consistently and confidently. In these settings, teachers are more likely to employ translanguaging, guided code-switching, and L1 explanations not as compensatory measures but as intentional pedagogical tools.

This finding reinforces the idea that teacher agency in multilingual instruction is strengthened when school leadership provides structured, ongoing professional development and affirms the legitimacy of multilingual practices.

Taken together, these effects illuminate a broader institutional pattern that mirrors long-standing concerns in Zambia’s education sector. While national language policy supports the use of familiar languages in early schooling, implementation remains uneven across schools due to differences in leadership capacity, resource allocation, teacher preparation, and monitoring structures. The present findings align with evidence from ECZ, UNICEF, and regional multilingual education research, all of which highlight that policy alone is insufficient to improve learning outcomes. Effective language-in-education reform depends on the extent to which schools translate policy into classroom-level routines. Schools with strong institutional cultures around multilingual pedagogy tend to empower teachers to use learners’ linguistic resources more effectively, while schools with weak support often struggle to sustain coherent practices, leaving teachers to navigate multilingual challenges without adequate guidance or tools.

The results also show that structural barriers—most notably the lack of multilingual instructional materials and limited teacher training—remain significant obstacles to successful multilingual instruction, particularly in rural and linguistically diverse areas. Without access to bilingual mathematics resources or meaningful professional support, teachers may default to English-only instruction, inadvertently exacerbating inequalities in mathematical understanding. Conversely, well-resourced schools foster an environment in which multilingual strategies are not only permissible but expected, ultimately enhancing learner engagement and performance. This institutional dynamic underscores the importance of viewing multilingual mathematics learning as a system-level issue rather than a classroom-level concern alone.

The implications of these findings for policy and educational planning are far-reaching. Strengthening implementation support for the LoI policy must become a priority, requiring the Ministry of Education and district offices to provide clear operational guidelines, monitoring frameworks, and school-level implementation tools. Expanding access to bilingual and local-language instructional materials would reduce linguistic barriers and give learners meaningful entry points into mathematical concepts. Teacher preparation programs—both pre-service and in-service—must incorporate robust modules on multilingual pedagogy, equipping teachers with concrete strategies for supporting learners in linguistically diverse contexts. School leaders also play a critical

role: cultivating cultures of collaborative inquiry, peer learning, and shared reflection encourages teachers to experiment with and refine multilingual instructional practices.

Overall, Objective 4 was fully achieved, and Hypothesis 4 received strong support. The results demonstrate that effective multilingual learning is shaped not only by individual learners and teachers, but also by the institutional environment within which mathematics instruction unfolds. Schools with strong language-in-education practices—clear policy implementation, accessible multilingual resources, and sustained professional development—create conditions that enhance mathematics achievement. These findings underscore the need for systemic, coordinated reforms that integrate policy, resources, and professional support to build linguistically inclusive mathematics education across Zambia’s school system.

21. Integrated Mediation and Cross-Level Pathways: Language as a Mediator

The integrated mediation analysis provides compelling evidence that language functions not merely as an instructional variable but as a central mediating mechanism through which individual, classroom, and school-level factors collectively shape mathematics achievement. The Bayesian mediation results revealed that a significant portion of the effect of learner-level English proficiency on mathematics performance operated indirectly through classroom language practices. Learners with stronger L2 proficiency were more able to engage productively in classroom discourse, participate meaningfully in problem-solving dialogue, and benefit from teacher explanations. In turn, classrooms where teachers actively employed translanguaging, strategic code-switching, and structured opportunities for learner talk amplified these advantages, creating learning conditions in which linguistic comprehension supported deeper mathematical processing. The indirect pathway from L2 proficiency through classroom practices to achievement supported by credible intervals excluding zero demonstrates that language practices function as an instructional bridge that connects linguistic access to conceptual understanding. This reinforces the core proposition of the study: language mediates the cognitive, social, and instructional processes through which mathematics learning occurs.

The mediation analysis further revealed that school-level factors influenced mathematics achievement largely through their effect on classroom language practices. Schools with stronger implementation of the Language of Instruction policy, more robust availability of local-language instructional materials, and sustained support for multilingual pedagogy were more likely to cultivate classroom environments where teachers used responsive language practices consistently and confidently. These institutional conditions created the structural foundation upon which effective multilingual teaching could flourish. The pathway from school policy to classroom practices to learner outcomes showed that the influence of institutional variables was not direct but instead operated by empowering teachers to create linguistically inclusive learning spaces. In other words, structural support produced

pedagogical coherence, which in turn produced improved learning outcomes. This finding underscores a key insight: multilingual teaching practices do not emerge spontaneously but are enabled—or constrained—by the institutional ecosystem in which teachers work.

This multilevel mediation pattern maps directly onto the conceptual model (Figure 1), which posits that learner characteristics (such as L1 and L2 proficiency), classroom linguistic environments, and school-level language structures interact dynamically in shaping mathematics learning. The model conceptualizes language as the conduit through which cognitive processes, instructional practices, and institutional policies intersect to influence outcomes. The empirical results strongly validate this framework. Classroom language practices served as a mediating layer that translated both learner linguistic resources and school-level supports into academic success. Learners benefited not only from their own linguistic abilities but also from the linguistic affordances engineered by teachers, which in turn depended on school-level structures and leadership.

Taken together, these findings affirm the central thesis of the study: language mediates learning. Language is not simply a variable among many; it is the medium through which mathematical ideas become accessible, communicable, and cognitively operable. The mediation results show that language and language practices are critical mechanisms that explain why some learners, classrooms, and schools perform better than others. Structural factors—such as policy implementation and access to local-language materials—shape the linguistic conditions of instruction. Teachers translate these conditions into pedagogical strategies. Learners, in turn, engage with mathematics through the linguistic environment created for them. This cascading pathway illustrates that improving mathematics achievement in multilingual contexts requires simultaneous attention to linguistic proficiency, instructional language practices, and institutional support systems. Ultimately, the integrated mediation analysis demonstrates that language is the thread that binds the entire multilevel educational ecology together, shaping how mathematical knowledge is accessed, interpreted, and mastered.

22. Robustness Checks and Model Comparison (Across Objectives)

A series of robustness checks and comparative assessments across the four Bayesian multilevel models provided strong evidence that the study’s substantive conclusions are stable and reliable. Model comparison using both the Widely Applicable Information Criterion (WAIC) and the Leave-One-Out Information Criterion (LOOIC) demonstrated incremental improvements in model performance as additional layers of linguistic context were incorporated. Model 1, which captured only learner-level predictors, provided a solid baseline but showed higher WAIC/LOOIC values relative to subsequent models. Model 2, which introduced teacher language practices, produced substantial reductions in both criteria, indicating that classroom linguistic scaffolding captured meaningful variance previously unexplained. Model 3 generated further

improvement with the inclusion of classroom-level linguistic composition variables, showing that the linguistic structure of classrooms—coherence, diversity, and teacher–learner language match contributed significantly to model fit. Model 4 produced the strongest performance overall, with the lowest WAIC and LOOIC values, confirming that school-level institutional supports for multilingual pedagogy added explanatory power beyond learner and classroom factors. The progressive decline in information-criterion scores across the models underscores the importance of adopting a multilevel, linguistically grounded analytic framework to understand mathematics achievement in multilingual settings.

Sensitivity analyses were also conducted to test the stability of the findings under different modelling assumptions. Several alternative prior specifications—including more informative priors, broader weakly informative priors, and priors centered at zero with varying degrees of dispersion—were applied to assess whether the strength or direction of the estimated effects changed materially. In all cases, posterior distributions for key predictors remained consistent in sign, magnitude, and credible interval coverage. Diagnostic checks confirmed strong convergence across chains, and posterior predictive checks showed that the models adequately reproduced observed data patterns. Additional tests involving alternative random-slope structures and the exclusion of small clusters yielded no meaningful deviation from the primary findings. These results indicate that the conclusions are not artifacts of particular prior choices or model configurations but reflect genuine, well-supported patterns in the data.

Taken together, the consistency in WAIC/LOOIC rankings, the stability of parameter estimates under varied priors, and the strong performance of posterior predictive diagnostics reinforce the credibility of the study’s conclusions. Across all robustness checks, the substantive interpretations for Objectives 1–4 remained stable: linguistic proficiency at the learner level, multilingual teaching practices at the classroom level, linguistic composition as a contextual factor, and institutional supports at the school level each played significant and complementary roles in shaping mathematics achievement. This convergence across analytic strategies enhances confidence in the robustness of the findings and affirms the central argument of the study—namely, that language operates as a powerful mediator of learning across multiple levels of the educational system.

23. Synthesis Across Objectives and Hypotheses

Taken together, the results across all four objectives produce a coherent and compelling picture of how language mediates mathematics learning within Zambia’s multilingual education system. Objective 1 and H1 received strong support: learner-level proficiency in both English (L2) and the home language (L1) emerged as significant predictors of mathematics achievement, underscoring that linguistic access forms the foundation upon which mathematical reasoning is built. Higher English proficiency improved performance directly, while strong L1 proficiency provided additional cognitive and linguistic support, validating Cummins’ Linguistic Interdependence Hypothesis and highlighting

the importance of leveraging existing linguistic strengths rather than relying solely on L2 instruction.

Objective 2 and H2 were also strongly supported. Teacher language practices—including translanguaging, code-switching, L1 explanations, and structured learner talk—had clear and meaningful effects on mathematics performance. These practices enhanced comprehension, reduced linguistic strain, and created richer opportunities for conceptual engagement. The findings closely align with Vygotsky’s Sociocultural Theory, which views language as the key mediational tool enabling learners to participate meaningfully in cognitive activity. Moreover, the strong positive effects of learner talk and teacher scaffolding reinforce the view that meaningful mathematical understanding is socially co-constructed through language.

Objective 3 and H3 received partial support. Linguistically coherent classrooms—where many learners shared a common L1—tended to exhibit higher mathematics achievement, and teacher–learner language match produced similar benefits. However, linguistic diversity showed negative effects only in contexts lacking strong multilingual teaching practices. When teachers actively supported multilingual meaning-making, diverse classrooms performed as well as homogeneous ones. This nuanced pattern reflects both the cognitive demands of navigating complex linguistic environments and the potential of diversity to enrich learning when pedagogically supported. These findings speak to cognitive load theory, which suggests that linguistic difficulty can consume working memory resources unless instructional scaffolding relieves that burden.

Objective 4 and H4 were fully supported, demonstrating that institutional conditions powerfully shape mathematics learning. Schools with strong implementation of the LoI policy, availability of local-language materials, and structured support for multilingual pedagogy consistently achieved better outcomes. These structural factors influenced learning indirectly by enabling teachers to adopt and sustain effective language practices. The mediated pathway from school-level supports → classroom practices → learner outcomes validates the study’s conceptual model and illustrates that multilingual education is not merely a classroom issue but a system-wide responsibility shaped by leadership, resources, and institutional culture.

Across all four hypotheses, H1, H2, and H4 were strongly supported, while H3 was partially supported due to the conditional nature of linguistic diversity effects. Collectively, these results affirm the central thesis that language operates as a mediator of learning across multiple levels of the educational system, connecting cognitive processes, instructional practices, and institutional structures. By integrating insights from sociocultural theory, linguistic interdependence, and cognitive load theory, the findings show that language is not a peripheral variable but the central mechanism through which mathematical meaning is accessed, negotiated, and mastered. This synthesis sets the stage for the next section, which will articulate the broader conclusions, implications, and recommendations arising from the study [30–34].

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