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RESEARCH ARTICLE

Effectiveness of Lesson Plan for Enhancing Mathematical Vocabulary and Conceptual Understanding in Secondary Education

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Abstract

Mathematical achievement is influenced not only by procedural competence but also by learners' ability to understand and use the specialized language of mathematics. In many secondary school contexts, difficulties in comprehending mathematical vocabulary constitute a significant barrier to conceptual understanding, particularly in solving word problems and interpreting abstract concepts. This study examined the effectiveness of a prototype lesson plan designed to enhance students' mathematical vocabulary through the integration of the Frayer Model and information and communication technology (ICT) resources. Using a quasi-experimental design, 216 Form Two students from secondary schools in Murang'a County, Kenya, participated in a ten-week instructional intervention. Learners in the experimental group engaged in structured vocabulary instruction that emphasized definitions, conceptual attributes, examples, non-examples, visual representations, and collaborative learning activities, while the control group received conventional definition-based instruction. Analysis of pre-test and post-test achievement data revealed that students exposed to the vocabulary-focused intervention achieved substantially higher levels of mathematical understanding and performance than their peers in the control group. The experimental group recorded significantly higher post-test scores ($M = 9.13$, $SD = 4.73$) than the control group ($M = 5.90$, $SD = 2.61$), with the difference reaching statistical significance, $t(214) = 6.21$, $p < .001$, and demonstrating a large practical effect (Cohen's $d = 0.85$). These findings suggest that mathematical vocabulary functions as a critical mediating factor in students' conceptual development and problem-solving capacity. The study argues that language-sensitive instructional approaches should occupy a more central position in mathematics education and that structured vocabulary instruction can provide an effective pathway for improving learning outcomes, particularly within competency-based educational frameworks. The proposed lesson model offers a promising pedagogical framework for supporting conceptual engagement, mathematical literacy, and meaningful participation in mathematics learning.

Citation

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1. INTRODUCTION

Mathematics is widely recognized as a foundational discipline for participation in contemporary knowledge societies. Beyond its traditional role in scientific and technological development, mathematical competence is increasingly regarded as an essential component of critical thinking, problem-solving, and informed decision-making in everyday life. International educational frameworks emphasize that successful engagement with mathematics requires not only procedural fluency but also the ability to interpret, communicate, and construct meaning through mathematical language. Consequently, mathematics learning is now understood as both a cognitive and a linguistic process.

Recent developments in mathematics education research have challenged the traditional assumption that mathematical achievement depends primarily on numerical and computational skills. Instead, scholars increasingly argue that learners' understanding of mathematical concepts is mediated through language, particularly through the acquisition and use of specialized mathematical vocabulary. Terms such as *integer*, *coefficient*, *polygon*, *equation*, and *probability* function not merely as labels but as conceptual tools that enable learners to organize knowledge, establish relationships between ideas, and engage in mathematical reasoning. Limited understanding of such terminology often restricts students' ability to interpret tasks, comprehend mathematical texts, and solve word problems effectively.

The relationship between language and mathematical learning has attracted growing attention within the broader field of disciplinary literacy. Research suggests that mathematical vocabulary constitutes a distinct linguistic register characterized by specialized meanings, symbolic representations, and unique syntactic structures. Unlike everyday language, mathematical terminology frequently refers to abstract entities that cannot be directly observed, making conceptual acquisition particularly challenging for learners. Studies conducted across diverse educational contexts have consistently reported significant associations between vocabulary knowledge and mathematics achievement, indicating that language proficiency serves as an important predictor of conceptual understanding and academic success.

Despite these insights, mathematics instruction in many educational systems continues to prioritize procedural knowledge and algorithmic competence while devoting comparatively limited attention to disciplinary language development. Traditional approaches frequently present mathematical terminology through isolated definitions that encourage memorization rather than conceptual understanding. Such practices often fail to support meaningful connections between vocabulary, representations, and problem-solving processes. As a result, students may demonstrate procedural competence while lacking a deeper understanding of the concepts underlying mathematical operations and relationships.

In response to these challenges, contemporary educational research has increasingly advocated for learner-centered instructional approaches that promote active construction of meaning. One of the most widely discussed strategies is the Frayer Model, a graphic-organizer framework that encourages students to explore concepts through definitions, characteristics, examples, and non-examples. Grounded in constructivist principles, the Frayer Model supports conceptual learning by enabling learners to examine concepts from multiple perspectives and establish meaningful cognitive connections. Previous studies have reported positive effects of this approach on vocabulary acquisition, conceptual retention, and academic achievement across various subject areas. Nevertheless, empirical investigations of its application within mathematics education remain relatively limited, particularly in African educational contexts.

The Kenyan education system has undergone substantial reforms aimed at improving learning outcomes through competency-based approaches, learner-centered pedagogies, and increased integration of digital technologies. However, national assessment reports continue to indicate persistent challenges in mathematics performance at the secondary school level. While numerous studies have examined factors such as instructional practices, teacher preparation, and learning resources, comparatively little attention has been given to the role of mathematical vocabulary in shaping students' conceptual understanding. Furthermore, there remains a scarcity of empirical evidence regarding the effectiveness of structured vocabulary instruction within Kenyan mathematics classrooms.

This gap is particularly evident in Murang'a County, where no published study has systematically examined how explicit mathematical vocabulary instruction influences learners' achievement and conceptual development. Addressing this limitation is important not only for advancing theoretical understanding of mathematics learning but also for informing evidence-based instructional practices within competency-based educational frameworks. Accordingly, the present study develops and evaluates a prototype lesson plan integrating the Frayer Model, collaborative learning strategies, and digital resources to support mathematical vocabulary acquisition among secondary school students. By investigating the impact of this intervention on mathematics achievement, the study contributes to ongoing discussions concerning the relationship between language, conceptual understanding, and effective mathematics instruction in contemporary educational settings.

2. LITERATURE REVIEW

2.1. Mathematical Language and Conceptual Understanding

Contemporary research increasingly recognizes mathematics as a language-intensive discipline in which learning is mediated through communication, interpretation, and meaning-making processes. While mathematical proficiency has traditionally been associated with computational skills and procedural fluency, recent scholarship emphasizes the central role of language in the construction of mathematical knowledge (Cai et al., 2023; Moschkovich, 2022). Mathematical concepts are communicated through specialized vocabulary, symbolic representations, and discourse practices that differ substantially from everyday language. Consequently, students' ability to understand mathematical terminology significantly influences their capacity to engage with abstract concepts and solve complex problems.

The relationship between language and mathematics has become a prominent area of inquiry within mathematics education research. Civil et al. (2021) argue that language should not be viewed merely as a vehicle for communicating mathematical ideas but as an essential resource for learning mathematics itself. Similarly, Fang and Schleppegrell (2022) contend that mathematical literacy involves the ability to interpret and use disciplinary language structures that facilitate conceptual reasoning and academic achievement. These perspectives are consistent with earlier work by Pimm (1987), who highlighted the distinctive linguistic characteristics of mathematical discourse and their implications for classroom learning.

Recent empirical evidence further supports the importance of mathematical language in conceptual development. García-Mila et al. (2023) found that students with stronger academic language proficiency demonstrated significantly higher levels of mathematical reasoning and conceptual understanding. Likewise, Schleppegrell (2023) reported that language development contributes directly to mathematics achievement by enabling learners to establish connections among concepts, representations, and problem-solving strategies. Collectively, these studies suggest that mathematical understanding is inseparable from the linguistic resources through which mathematical ideas are expressed and interpreted.

2.2. Mathematical Vocabulary and Academic Achievement

Among the various dimensions of mathematical language, vocabulary has emerged as one of the strongest predictors of students' academic success. Mathematical vocabulary consists of specialized terms that represent abstract concepts, relationships, and procedures. Unlike many words encountered in everyday communication, mathematical terms often possess precise technical meanings that require explicit instruction and contextualized learning experiences.

Research consistently demonstrates positive associations between vocabulary knowledge and mathematics achievement. In a comprehensive meta-analysis, Bicer et al. (2021) concluded that mathematical vocabulary significantly predicts students' performance in mathematical problem solving and conceptual tasks. Similarly, Adams et al. (2022), in a systematic review of secondary mathematics classrooms, found that vocabulary knowledge contributes substantially to learners' understanding of mathematical concepts and their ability to engage in higher-order reasoning.

Earlier investigations also support these findings. Monroe and Orme (2002) observed that explicit vocabulary instruction enhances students' comprehension of mathematical concepts and improves classroom participation. Stahl and Fairbanks (1986) demonstrated that systematic vocabulary instruction can produce substantial gains in academic achievement across subject areas, including mathematics. More recently, Doabler et al. (2021) reported that targeted mathematics vocabulary interventions improved both conceptual understanding and problem-solving performance among secondary school learners.

The growing body of evidence suggests that mathematical vocabulary serves as a bridge between language and conceptual knowledge. Students who understand mathematical terminology are better positioned to interpret problem statements, recognize conceptual relationships, and apply mathematical procedures appropriately. Conversely, deficiencies in vocabulary knowledge often impede conceptual development and contribute to persistent learning difficulties.

2.3. The Frayer Model and Vocabulary Instruction

One instructional approach that has received considerable attention in vocabulary education is the Frayer Model. Originally developed by Frayer et al. (1969), the model employs a graphic organizer that encourages learners to analyze concepts through definitions, characteristics, examples, and non-examples. Grounded in constructivist learning theory, the Frayer Model promotes active engagement with concepts and supports deeper cognitive processing than traditional memorization-based approaches.

The pedagogical value of the Frayer Model has been documented across diverse educational settings. Russell et al. (2013) argue that the model facilitates conceptual understanding by enabling students to examine concepts from multiple perspectives and establish meaningful cognitive connections. Riksadianti (2021) similarly found that the Frayer Model enhances vocabulary acquisition and long-term retention by encouraging learners to actively construct meaning rather than passively receive information.

In mathematics education, the use of graphic organizers has shown particular promise. Van Garderen et al. (2021) reported that visual learning tools support conceptual understanding by helping students organize information and identify relationships among mathematical ideas. Furthermore, Prediger et al. (2022) demonstrated that language-responsive instructional approaches significantly improve conceptual learning outcomes in mathematics classrooms. These findings suggest that integrating vocabulary instruction with visual and interactive learning strategies may offer an effective means of addressing language-related barriers to mathematical understanding.

Research conducted in different educational contexts also provides evidence for the effectiveness of the Frayer Model in mathematics learning. Madzore (2023) found that mastery of mathematical vocabulary was strongly associated with improved conceptual understanding and achievement among secondary school students. Such findings reinforce the argument that structured vocabulary instruction can contribute meaningfully to mathematical learning outcomes.

2.4. Research Gap and Theoretical Framework

Despite growing international interest in mathematical language and vocabulary instruction, empirical evidence remains unevenly distributed across educational contexts. Most existing studies have been conducted in North America, Europe, and selected Asian countries, while relatively few investigations have examined the effectiveness of structured mathematical vocabulary instruction in African secondary schools. Furthermore, many studies focus on general literacy interventions rather than discipline-specific vocabulary approaches designed explicitly for mathematics education.

Within the Kenyan context, research on mathematics achievement has primarily concentrated on instructional practices, teacher effectiveness, curriculum implementation, and resource availability. Comparatively little attention has been devoted to examining the role of mathematical vocabulary in supporting conceptual understanding and academic performance. Consequently, there remains limited evidence regarding how structured vocabulary interventions, particularly those employing the Frayer Model and digital learning resources, influence mathematics achievement among secondary school learners.

The present study addresses this gap by developing and evaluating a prototype lesson plan that integrates explicit vocabulary instruction, graphic organizers, and ICT-supported learning experiences. The study is theoretically informed by constructivist perspectives on learning and disciplinary literacy frameworks, both of which emphasize the active construction of meaning through language-mediated interactions. By investigating the relationship between vocabulary instruction and mathematics achievement in Kenyan secondary schools, the study contributes to the expanding literature on mathematical language, conceptual understanding, and evidence-based instructional innovation.

2.5. Research Aim

The primary aim of this study is to investigate the effectiveness of a structured mathematical vocabulary instructional framework based on the Frayer Model in enhancing secondary school students' conceptual understanding and mathematics achievement. Specifically, the study seeks to develop, implement, and evaluate an ICT-supported prototype lesson plan that integrates vocabulary-focused learning strategies within mathematics instruction. By examining the relationship between explicit vocabulary instruction and students' learning outcomes, the study aims to contribute empirical evidence to the growing body of research on disciplinary literacy, mathematical language development, and language-responsive mathematics pedagogy in secondary education.

Table 1. *Trends in KCSE Mathematics Performance, Candidate Participation, and Gender Disparities in Kenya (2018–2024)*

Year	Total Candidates	National Mean Score (%)	Female Mean Score (%)	Male Mean Score (%)	Gender Gap
2024	962,512	23.84	21.92	25.76	3.84
2023	895,909	22.70	20.83	24.57	3.74
2022	877,293	15.16	13.61	16.69	3.08
2021	822,466	20.00	18.67	21.33	2.66
2020	746,914	18.35	16.64	20.06	3.42
2019	694,484	27.50	25.49	29.51	4.02
2018	663,066	25.71	23.05	28.24	5.19

Note. Gender gap was calculated as the difference between the mean mathematics scores of male and female candidates. Data compiled from annual reports of the Kenya National Bureau of Statistics (KNBS, 2024) and the Kenya National Examinations Council (KNEC, 2018–2024).

3. MATERIALS AND METHODS

3.1. Research Design

This study employed a quasi-experimental pretest–posttest nonequivalent control group design to examine the effectiveness of structured mathematical vocabulary instruction based on the Frayer Model. The design was selected because random assignment of students to experimental conditions was not feasible within the participating schools. Nevertheless, the use of pretest measures enabled the establishment of baseline equivalence between groups and strengthened the internal validity of the study. The research design is represented as follows:

Experimental Group: $O_1 \rightarrow X \rightarrow O_3$

Control Group: $O_2 \rightarrow - \rightarrow O_4$

where O_1 and O_2 represent pretest measurements, X denotes the instructional intervention, and O_3 and O_4 represent post-test measurements.

3.2. Research Setting and Participants

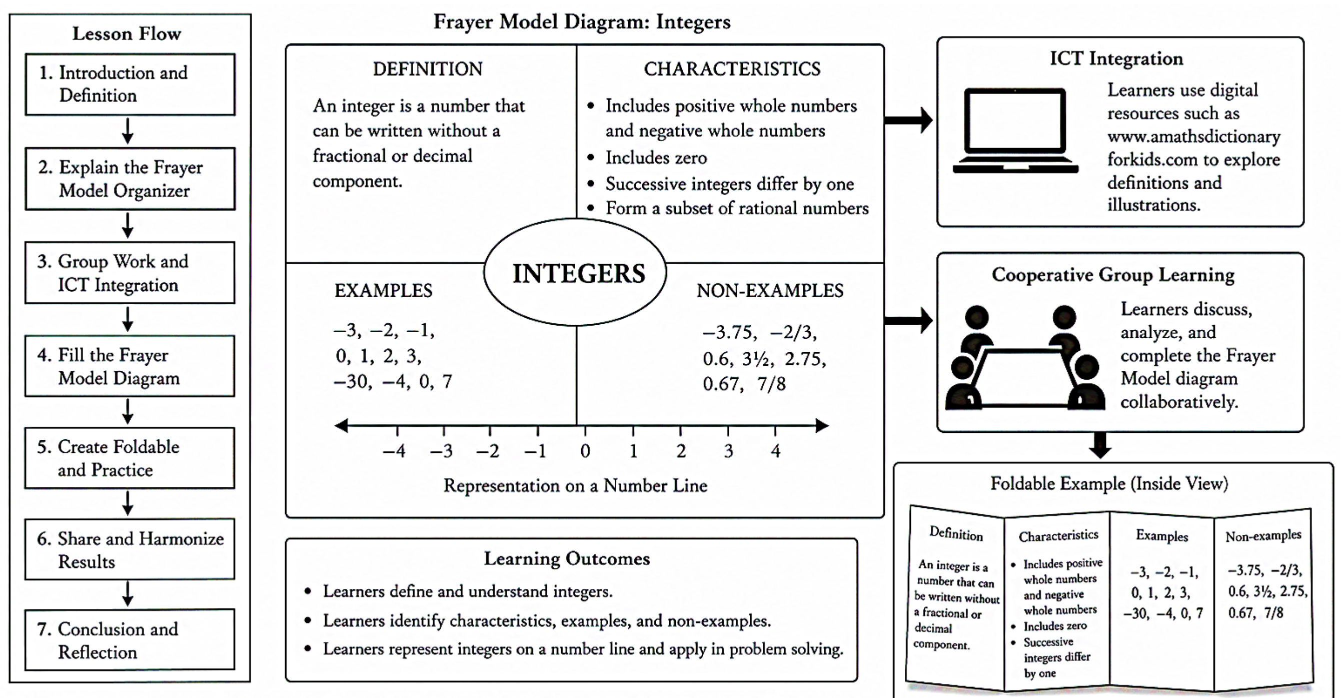
The study was conducted in Kahuro Sub-County, Murang'a County, Kenya. Two public secondary schools were purposively selected based on comparable academic performance, similar student demographics, and access to basic ICT facilities. These criteria were intended to minimize contextual variation and enhance comparability across learning environments.

The study involved 216 Form Two students distributed across four intact classes. Two classes were assigned to the experimental condition and two classes served as controls. In addition, six mathematics teachers participated in the study and were responsible for implementing the instructional intervention. All participating teachers possessed formal teaching qualifications and experience in secondary mathematics education.

3.3. Instructional Intervention

The intervention lasted ten weeks and focused on the explicit teaching of mathematical vocabulary through the Frayer Model. Students in the experimental group received structured instruction that integrated concept definitions, critical attributes, examples, non-examples, visual representations, and collaborative learning activities. The instructional framework was further supported by digital learning resources and online mathematical vocabulary tools, allowing students to engage with concepts through multiple representations and modalities.

Figure 1. Prototype Lesson Plan Based on the Frayer Model for Mathematical Vocabulary Instruction: The Concept of Integers



Note. The figure presents the sequence of instructional steps and the structure of the Frayer Model used to promote understanding of the concept "integers".

Source: Developed by the author based on Frayer, Fredrick, and Klausmeier (1969), adapted for mathematics vocabulary instruction and aligned with learner-centered and ICT-supported pedagogical principles.

A prototype lesson plan consisting of sixty instructional sessions was developed collaboratively by the researcher and participating teachers. The lesson sequence was aligned with the principles of learner-centered pedagogy and incorporated elements of the ASEI-PDSI approach, emphasizing activity-based learning, experimentation, communication, and problem-solving. Core competencies promoted throughout the intervention included critical thinking, collaboration, digital literacy, and mathematical communication.

Students in the control group continued to receive conventional mathematics instruction, which primarily relied on teacher explanations, direct definitions of terminology, and routine practice exercises. The distinction between instructional approaches enabled the investigation of the specific contribution of structured vocabulary instruction to mathematics learning outcomes.

Teacher Preparation

Prior to implementation, participating teachers received professional development training on the objectives, procedures, and pedagogical principles of the intervention. Training sessions employed a lesson-study approach involving collaborative planning, classroom implementation, peer observation, and reflective discussion. This process was intended to ensure consistency in instructional delivery and fidelity of implementation across experimental classrooms.

3.4. Instruments

Data were collected using two primary instruments.

Mathematics Achievement Tests

The Pre-Test Students' Mathematics Achievement Test (PRESMAT) and Post-Test Students' Mathematics Achievement Test (POSMAT) were developed to assess students' conceptual understanding and mathematics achievement. Test items were aligned with curriculum objectives, Bloom's revised taxonomy, and selected KCSE examination standards.

Students' Mathematical Vocabulary Dictionary (SMVD)

The Students' Mathematical Vocabulary Dictionary served as both an instructional and monitoring tool. It enabled learners to record definitions, examples, visual representations, and conceptual relationships associated with mathematical terms introduced during the intervention.

3.5. Data Collection Procedures

Data collection occurred over an eleven-week period. During Week 1, participants completed the PRESMAT to establish baseline performance levels. The instructional intervention was subsequently implemented for ten weeks. At the conclusion of the intervention, all participants completed the POSMAT under standardized testing conditions.

3.6. Data Analysis

Data were analyzed using IBM SPSS Statistics Version 25. Descriptive statistics, including means and standard deviations, were calculated to summarize student performance. Independent-samples t-tests were conducted to examine differences between the experimental and control groups. Effect sizes were calculated using Cohen's d to determine the practical significance of observed differences. Statistical significance was evaluated at the .05 level.

3.7. Ethical Considerations

Ethical approval for the study was obtained from the National Commission for Science, Technology and Innovation (NACOSTI) and the Kenyatta University Ethics Review Committee. Informed consent was obtained from all participants and their guardians prior to data collection. Participation was voluntary, confidentiality was maintained throughout the study, and participants retained the right to withdraw at any stage without penalty.

4. RESULTS

The instructional intervention was implemented over a ten-week period and followed a structured sequence designed to promote active engagement with mathematical vocabulary. The instructional process consisted of eight interconnected stages: (a) introduction and definition of the target mathematical concept; (b) explanation of the Frayer Model graphic organizer; (c) formation of collaborative learning groups; (d) guided completion of concept diagrams using digital and print resources; (e) vocabulary practice and reinforcement activities; (f) development of student-generated foldables; (g) peer sharing and discussion of completed conceptual frameworks; and (h) whole-class synthesis facilitated by the teacher. This sequence was intended to support conceptual learning through multiple representations, collaborative inquiry, and language-rich mathematical interactions.

Students completed the Pre-Test Students' Mathematics Achievement Test (PRESMAT) prior to the intervention and the Post-Test Students' Mathematics Achievement Test (POSMAT) at the conclusion of the study. The descriptive results are presented in Table 1.

Table 2. Results for PRESMAT and POSMAT for Control and Experimental Groups

Groups	**N**	**PRESMAT Mean**	**PRESMAT SD**	**POSMAT Mean**	**POSMAT SD**	**Cohen's d (Within Groups)**	**Effect Size**	**Cohen's d (Between Groups)**	**Effect Size**
Control	108	5.79	2.64	5.90	2.61	0.04	Negligible	–	–
Experimental	108	5.74	2.17	9.13	4.73	0.92	Large	0.85	Large

As shown in Table 1, both groups demonstrated comparable levels of mathematics achievement at the beginning of the study, indicating satisfactory baseline equivalence. The control group recorded a pretest mean score of 5.79 (SD = 2.64), while the experimental group achieved a mean score of 5.74 (SD = 2.17).

Following the intervention, notable differences emerged between the groups. The experimental group achieved a substantially higher post-test mean score (M = 9.13, SD = 4.73) compared with the control group (M = 5.90, SD = 2.61). The improvement observed in the control group was minimal, corresponding to a negligible within-group effect size (Cohen's d = 0.04). In contrast, students exposed to the Frayer Model-based vocabulary intervention demonstrated a substantial increase in achievement, yielding a large within-group effect size (Cohen's d = 0.92).

These findings suggest that structured mathematical vocabulary instruction contributed meaningfully to students' conceptual understanding and mathematics achievement. The integration of the Frayer Model, learner-centered activities, and ICT-supported resources appears to have enhanced learners' ability to understand and apply mathematical concepts more effectively than conventional instructional approaches.

To determine whether the observed differences between groups were statistically significant, an independent-samples t-test was conducted. The results are presented in Table 2.

Table 3. Independent-Samples t-Test Comparing Post-Test Achievement Between Experimental and Control Groups

Groups	n	POSMAT Mean	SD	t	df	p-value	Cohen's d	Effect Size
Control	108	5.90	2.61	–	–	–	–	–
Experimental	108	9.13	4.73	6.21	214	< .001	0.85	Large

The independent-samples t-test revealed a statistically significant difference between the post-test achievement scores of the experimental and control groups, $t(214) = 6.21$, $p < .001$. Consequently, the null hypothesis (H_{01}) was rejected, and the alternative hypothesis (H_{a1}) was accepted. Students who received structured vocabulary instruction through the Frayer Model achieved significantly higher mathematics scores than students who received conventional definition-based instruction.

Beyond statistical significance, the intervention produced a large practical effect (Cohen's d = 0.85), indicating that the observed gains were educationally meaningful. According to conventional interpretations of effect sizes, this magnitude suggests a substantial impact of the intervention on student learning outcomes. The results therefore provide strong evidence that mathematical vocabulary instruction can function as a critical mechanism for enhancing conceptual understanding and mathematical performance.

The findings are consistent with previous international research emphasizing the importance of disciplinary language in mathematics learning. Madzore (2023) reported a significant relationship between mathematical vocabulary knowledge and achievement among secondary school learners, while Mohammed (2019) found that Frayer Model-based instruction improved students' acquisition of mathematical concepts. Similarly, Monroe and Orme (2002) and Stahl and Fairbanks (1986) demonstrated that explicit vocabulary instruction contributes positively to academic achievement by facilitating deeper conceptual processing and retention. The present findings extend this body of evidence by demonstrating the effectiveness of structured mathematical vocabulary instruction within the Kenyan secondary school context.

Table.4. Descriptive Statistics (2018–2023)

Indicator	Value
Mean Candidate Enrolment	783,355
Mean National Mathematics Score	21.57
Mean Female Score	19.72
Mean Male Score	23.40
Average Gender Gap	3.69
Highest National Mean Score	27.50 (2019)
Lowest National Mean Score	15.16 (2022)
Enrolment Growth (2018–2023)	+35.1%

Note. The gender gap was calculated as the difference between the average mathematics scores of male and female candidates. Candidate enrolment increased substantially during the study period, while mathematics achievement remained relatively unstable. Despite fluctuations in national performance, male candidates consistently outperformed female candidates across all years examined. Data adapted from the Kenya National Bureau of Statistics (KNBS, 2023, 2024) and Kenya National Examinations Council (KNEC) annual reports.

Overall, the results indicate that mathematical vocabulary should not be regarded as a peripheral component of mathematics instruction but rather as a central element of conceptual development and academic success. The substantial gains achieved by the experimental group suggest that language-responsive pedagogical approaches can play a significant role in improving mathematics achievement and supporting meaningful learning outcomes in secondary education.

5. DISCUSSION

The primary objective of this study was to evaluate the effectiveness of a structured mathematical vocabulary instructional framework based on the Frayer Model in enhancing secondary school students' conceptual understanding and mathematics achievement. The findings demonstrated that students who participated in the intervention achieved significantly higher post-test scores than those receiving conventional instruction, providing empirical support for the growing body of literature emphasizing the central role of disciplinary language in mathematics learning.

The substantial improvement observed among students in the experimental group suggests that mathematical vocabulary functions as more than a supplementary component of instruction; rather, it serves as a critical mechanism through which learners construct, organize, and communicate mathematical knowledge. Contemporary research increasingly views mathematics as a language-rich discipline in which conceptual understanding is mediated through specialized terminology, representations, and discourse practices (Cai et al., 2023; Moschkovich, 2022). The present findings reinforce this perspective by demonstrating that explicit vocabulary instruction can significantly improve students' ability to understand and apply mathematical concepts.

One possible explanation for the effectiveness of the intervention lies in the cognitive structure of the Frayer Model itself. Unlike traditional definition-based approaches, the Frayer Model requires learners to engage with concepts through multiple dimensions, including definitions, characteristics, examples, and non-examples. This process encourages active meaning construction and promotes deeper conceptual processing. By requiring students to distinguish relevant from irrelevant attributes and connect new terminology to existing knowledge structures, the model supports relational understanding rather than rote memorization. Such findings are consistent with constructivist learning theory, which posits that meaningful learning occurs when learners actively integrate new information into pre-existing cognitive frameworks.

The findings also align with previous empirical studies investigating mathematical vocabulary instruction. Bicer et al. (2021) reported that mathematical vocabulary knowledge is a significant predictor of students' problem-solving performance, while Adams et al. (2022) identified vocabulary mastery as an important determinant of conceptual understanding in secondary mathematics classrooms. Similarly, Doabler et al. (2021) found that explicit vocabulary interventions contributed to measurable improvements in mathematical reasoning and achievement. The current study extends these findings by providing evidence from the Kenyan secondary education context, where empirical investigations of vocabulary-based mathematics instruction remain limited.

Another important contribution of the intervention was the integration of ICT-supported learning resources. The combination of graphic organizers, digital vocabulary tools, and collaborative learning activities provided students with multiple opportunities to engage with mathematical concepts through visual, textual, and interactive representations. Previous studies have shown that multimodal learning environments enhance conceptual development by reducing cognitive barriers and supporting diverse learning styles (Prediger et al., 2022; Fang & Schleppegrell, 2022). The present findings suggest that technology-enhanced vocabulary instruction may represent an effective strategy for improving mathematics learning outcomes within competency-based educational frameworks.

The negligible improvement observed in the control group provides further evidence of the limitations associated with conventional definition-only instructional approaches. While such methods may facilitate short-term recall of terminology, they often fail to promote the deeper conceptual understanding required for meaningful mathematical reasoning. In contrast, the Frayer Model encouraged students to engage actively with mathematical language, compare concepts, identify relationships, and construct personal meaning. These processes appear to have contributed significantly to the higher levels of achievement observed among students in the experimental group.

From a practical perspective, the findings highlight the importance of integrating mathematical language instruction into mainstream mathematics curricula. Educational reforms frequently emphasize problem-solving, critical thinking, and conceptual understanding; however, these goals may be difficult to achieve if learners lack sufficient mastery of the language through which mathematical ideas are expressed. Consequently, mathematics teachers should be encouraged to adopt language-responsive pedagogical approaches that explicitly address vocabulary development alongside procedural and conceptual instruction.

Although the results are promising, several limitations should be acknowledged. The study was conducted within a limited geographical area and involved only two secondary schools, which may restrict the generalizability of the findings. Additionally, the intervention focused primarily on selected mathematical vocabulary terms over a relatively short instructional period. Future research could investigate the long-term effects of vocabulary-based instruction across different mathematical domains, educational levels, and sociocultural contexts. Further studies employing larger and more diverse samples would also strengthen the evidence base for language-responsive mathematics instruction.

6. CONCLUSION

This study demonstrated that structured mathematical vocabulary instruction based on the Frayer Model can significantly enhance students' conceptual understanding and mathematics achievement. Learners who participated in the intervention achieved substantially higher post-test scores than those receiving conventional definition-based instruction, indicating that vocabulary development plays a crucial role in mathematical learning.

The findings support contemporary perspectives that conceptual understanding in mathematics is closely linked to students' ability to understand and use disciplinary language effectively. By combining explicit vocabulary instruction, graphic organizers, collaborative learning activities, and ICT-supported resources, the intervention created opportunities for deeper conceptual engagement and more meaningful learning experiences.

The study further suggests that mathematical vocabulary should be viewed as a core component of mathematics education rather than a peripheral instructional element. Language-responsive approaches such as the Frayer Model provide practical mechanisms for addressing conceptual difficulties, improving problem-solving performance, and fostering mathematical literacy among secondary school learners.

From a policy perspective, curriculum developers, teacher educators, and educational administrators should consider incorporating structured vocabulary instruction into mathematics curricula and professional development programs. Such initiatives may contribute to improved learning outcomes and support broader educational goals related to conceptual understanding, critical thinking, and equitable access to quality mathematics education.

Overall, the findings provide empirical evidence that strengthening mathematical language can serve as an effective pathway toward improving mathematics achievement and promoting meaningful participation in contemporary mathematics classrooms.

Instrument validity was established through expert review by specialists in mathematics education and educational research from Kenyatta University. A pilot study involving 20 Form Two students from a comparable school outside the study area was conducted to assess clarity, relevance, and instrument functionality.

Internal consistency reliability was assessed using the Kuder–Richardson Formula 20 (KR-20). Reliability coefficients were .83 for PRESMAT and .89 for POSMAT, exceeding the recommended threshold of .70 and indicating satisfactory reliability for research purposes.

7. DECLARATIONS

Ethics Approval

This study was conducted in accordance with the ethical principles governing research involving human participants and complied with the regulations of the National Commission for Science, Technology and Innovation (NACOSTI), Kenya. Ethical approval was obtained from the Kenyatta University Ethics Review Committee and the National Commission for Science, Technology and Innovation prior to the commencement of data collection. All research procedures adhered to institutional and national guidelines for educational research.

Informed Consent

Written informed consent was obtained from all participants and, where applicable, from their parents or legal guardians before participation in the study. Participants were informed about the purpose of the research, the voluntary nature of participation, their right to withdraw at any stage without consequences, and the measures implemented to ensure confidentiality and anonymity.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflict of Interest

The author declares that there are no competing financial, professional, institutional, or personal interests that could have influenced the design, implementation, analysis, or interpretation of the findings reported in this study.

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Author Contributions

Yang Ying: Conceptualization, methodology, supervision, manuscript preparation.

Naduri Mutungi: Data collection, implementation of the intervention, statistical analysis, manuscript drafting.

Both authors reviewed and approved the final manuscript.

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