

The Effect of Using GeoGebra on Grade 11 Students' Learning of Measurement at a Selected Secondary School in Guyana

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ABSTRACT

Grade 11 students in Mahaica-Berbice, Guyana, consistently demonstrate unsatisfactory achievement in CSEC Mathematics measurement concepts, particularly in visualizing properties of geometric solids and calculating surface area and volume. This quantitative quasi-experimental study employed a Non-Equivalent Pre-test–Post-test Control Group Design with two intact Grade 11 classes ($n = 31$ per group) at a selected secondary school. The experimental group received four weeks of GeoGebra-assisted instruction while the control group received traditional instruction on identical CSEC-aligned content. The experimental group recorded a higher post-test mean ($M = 18.74$, $SD = 4.54$) than the control group ($M = 16.61$, $SD = 4.32$), yielding a mean difference of 2.13 marks and a small-to-medium effect size ($d = 0.481$), though the difference did not reach statistical significance, $t(60) = 1.892$, $p = .063$. The finding tentatively suggest that GeoGebra-assisted instruction may offer a potentially beneficial, accessible, and theoretically grounded approach to measurement instruction in resource-constrained Caribbean secondary schools, warranting further investigation with larger samples.

Keywords: GeoGebra, Measurement, 2D shapes, Solids, CSEC Mathematics

INTRODUCTION

Introduction to the Study

Grade 11 students in Guyana consistently struggle with measurement concepts in CSEC Mathematics, particularly in visualizing and identifying properties of shapes, and calculating surface area, and volume (Baksh et al., 2025; Cameron et al., 2024). Traditional instructional methods that rely on static diagrams and rote memorization fail to develop necessary conceptual understanding of measurement topics (Jelatu et al., 2018). This quantitative quasi-experimental study investigated whether GeoGebra-assisted instruction improved Grade 11 students' measurement achievement at a selected secondary school in Guyana compared to traditional instruction.

Background

CSEC Mathematics in CARICOM confronts critical challenges that directly impact grade 11 students' academic results and future opportunities (Lewis, 2023). The students preparing for the Caribbean Secondary Education Certificate (CSEC) Mathematics examinations encounter difficulties with measurement concepts, including properties of two-dimensional (2D) and three-dimensional (3D) shapes, surface area, and volume of right solids (George, 2023). These challenges have profound implications for students' pursuit of needful careers in science, technology, engineering, and mathematics (STEM) fields within CARICOM. The study of measurement represents a total weighting of 11 % of the CSEC mathematics curriculum (Caribbean Examinations Council, 2025a, 2025b; George, 2023). Students consistently struggle to visualize and sketch geometric shapes and apply appropriate formulae to solve standardized examination-style mensuration problems (Sweeney & George, 2024). Traditional teaching methods, which rely heavily on textbook questions

with pictures, diagrams and rote memorization, compound these challenges. These pedagogical practices have produced persistently low achievement rates in measurement topics on regional examinations, that creates a cycle of mathematics anxiety and disengagement among secondary school students (Mania & Alam, 2021).

This research held significance for stakeholders, particularly at the selected school, as well as, schools with similar demographic profiles within Guyana. Students could improve knowledge and skills of measurement concepts that could lead to enhanced CSEC Mathematics performance, increased confidence and attitude towards mathematical problem-solving, and better preparation for tertiary education or technical vocations. Teachers' evidence-based insights into GeoGebra-assisted instruction could inform professional development and pedagogy. Moreover, for the education administrators, the findings could guide decisions regarding resource allocation, curriculum development, and technology integration strategies in resource-constrained schools. The research could contribute to the broader goal of promoting STEM programmes in Mahaica-Berbice, Guyana, where innovative and cost-effective solutions remain urgently needed.

Researchers in developed nations have extensively studied the integration of GeoGebra to teach and learn mathematics, with considerable research demonstrating the potential impact of the software in transforming students' learning experiences (Adelabu et al., 2022; Rahman et al., 2025). GeoGebra has emerged as a prominent tool for enhancing mathematical visualization and conceptual understanding (Martinez, 2017). Uwurukundo et al. (2020) expounded on the theoretical foundation for GeoGebra's pedagogical value and demonstrated the software's dynamic and interactive environment enables students to manipulate mathematical objects and observe real-time relationships between algebraic and geometric representations. This dual representation capability addresses fundamental challenges in measurement strand, where students often struggle to connect abstract formulae with concrete spatial understanding. Similarly, Tamam and Dasari (2021) found that GeoGebra-assisted instruction significantly improved students' ability to visualize geometric transformations and develop intuitive understanding of mathematical relationships that remained opaque in textbooks.

Researchers have documented the effectiveness of GeoGebra in teaching measurement concepts specifically across various educational contexts. Furthermore, Zulnaidi et al. (2020) conducted experimental research, showing that students using GeoGebra demonstrated superior performance in calculating area and volume compared to control groups receiving traditional instruction. Their research showed that by presenting three-dimensional objects from different viewpoints, the software enabled students to dispel widespread misunderstandings about surface area and volume relationships. Jelatu et al. (2018) corroborated these findings in their study done at Malaysian secondary schools, which reported that GeoGebra integration led to statistically significant improvements in geometry achievement and enhanced positive attitudes toward mathematics learning.

Despite international research, scholars have noted the limitations of generalizing findings from developed nations to Caribbean and Latin America countries (Leacock, 2015; Orville & Disraeli, 2022). Factors such as limited technological infrastructure, teacher preparation, internet connectivity, and culturally specific pedagogical traditions create unique implementation challenges that research conducted in well-resourced educational systems may not adequately address (Leacock, 2015). Moreover, the literature available provides compelling evidence for GeoGebra's effectiveness in the teaching and learning of mathematics and STEM related subjects. Additionally, researchers have conducted limited studies on GeoGebra effectiveness in the CARICOM educational context, particularly at the 11th grade level, where students prepare for CSEC Mathematics (Liburd & Jen, 2021). This gap carries particular significance given the distinct characteristics of Caribbean mathematics curriculum, including specific curriculum requirements aligned with regional examinations, resource constraints common in developing nations, and unique cultural contexts that influence teaching and learning practices. The existing research base lacks empirical evidence addressing how educators can effectively implement GeoGebra in resource-constrained Caribbean secondary schools, where factors such as irregular electricity supply, limited computer access, inadequate teacher training in educational technology, cultural barriers and large class sizes constitute implementation barriers that developed countries do not commonly encounter. Furthermore, previous studies have predominantly focused on younger students or higher education settings, leaving a critical knowledge gap regarding Grade 11 students who face the

immediate pressure of high-stakes regional examinations that determine their educational and career trajectories.

This study sought to address a significant gap in understanding how GeoGebra can improve measurement learning outcomes in resource-constrained Caribbean educational settings. The measurement strand of the CSEC Mathematics syllabus presents particular challenges for Guyanese students, with regional examination statistics consistently showing lower performance in mensuration compared to other mathematical strands (Caribbean Examinations Council, 2025b). However, no systematic research has investigated whether GeoGebra instruction can target this problematic area to produce measurable improvements in students' achievement within the Guyanese educational context. This research addressed this gap by examining both the effectiveness and the practical feasibility of GeoGebra implementation in a Guyanese secondary school setting.

Problem statement

Grade 11 students at the selected secondary school consistently demonstrate unsatisfactory achievement in measurement concepts, particularly in identifying properties and calculating surface area and volume of right solids and attempting problem-solving exercises on the same (Okolo McFarlane-Jhingoree, personal communication, November 6, 2025). Traditional instruction relies heavily on textbook examples, static diagrams, still pictures and rote memorization that fail to develop the conceptual understanding necessary for success on Caribbean Secondary Education Certificate (CSEC) Mathematics examinations. Despite increasing emphasis on Higher-Order Thinking Skills (HOTS) in mathematics curricula, classroom implementation remains limited and inconsistent (Ega et al., 2025). The utility of traditional methods for teaching measurement does not sufficiently address Higher-Order Thinking Skills (HOTS), which are a critical component of the CSEC mathematics curriculum.

Despite international literature on GeoGebra's effectiveness in improving geometry and measurement learning outcomes, National Centre for Educational Resource and Development (NCERD) have not systematically implemented or evaluated the GeoGebra-assisted instruction (Leon Beaton, personal communication, November 8, 2025). This leaves teachers to struggle with pedagogical methods that have repeatedly yielded unsatisfactory results. The literature highlights GeoGebra's effectiveness in addressing visualization and conceptual understanding challenges similar to those Guyanese students' experience, yet these findings emerge almost exclusively from developed nations, creating a contradiction between documented best practices and Caribbean and Latin America classroom implementation. A study done by Wassie and Zergaw (2019) found secondary school students using GeoGebra achieved scores 18.7% higher than control groups in measurement concepts. Studies on GeoGebra use in Indonesia demonstrate that students who learned Geometry through GeoGebra achieved significantly higher mastery levels compared to those taught through traditional instruction, highlighting its effectiveness for topics that students commonly find challenging (Siswanto et al., 2024). Jelatu et al. (2018) demonstrated that GeoGebra reduced mathematics anxiety and increased self-efficacy through immediate visual feedback.

Sahin and Yilmaz (2020) found that poorly implemented technology integration produced worse outcomes than traditional instruction, requiring adequate teacher training and curriculum alignment. Hillmayr et al. (2020) concluded that digital tool effectiveness depends heavily on contextual factors, including infrastructure, teacher expertise, and cultural appropriateness. There is limited Caribbean-specific research; Guyanese educators cannot determine whether GeoGebra implementation will replicate international outcomes or how to adapt it for resource-constrained settings. The problem exists at the intersection of documented best practices and local challenges. Guyanese students experience unsatisfactory achievement using methods that are less effective than available alternatives, yet educators lack context-specific evidence to justify technology integration. This study investigated whether GeoGebra's documented international effectiveness transfers to the selected school or schools with similar academic achievement in measurement in Guyana.

Purpose of the Study

The purpose of this quantitative quasi-experimental study was to determine the effect of GeoGebra-assisted instruction on Grade 11 students' achievement in measurement concepts at a selected secondary school in

Guyana. This study compared the measurement achievement outcomes of students receiving GeoGebra-assisted instruction (experimental group) with those receiving traditional instruction (control group) over a 4-week period. The independent variable was the instructional method (GeoGebra-assisted instruction versus traditional instruction), and the dependent variable was student achievement, measured through pre-tests and post-tests on validated measurement assessments covering properties of two-dimensional and three-dimensional shapes, surface area, and volume of right solids. Testing the systematic effectiveness of GeoGebra implementation within a resource-constrained Caribbean educational context, this study addressed the gap between documented international best practices in technology-enhanced mathematics instruction and the persistent challenges facing Guyanese secondary students at the selected secondary school preparing for CSEC Mathematics examinations. This study also aimed to inform instructional decision-making for mathematics educators in resource-constrained secondary schools by generating context-specific empirical evidence on the feasibility and effectiveness of GeoGebra within the Guyana's secondary school.

Research Question and Hypotheses

The research question guided the investigation into the comparative effectiveness of two instructional approaches for teaching measurement. The study examined whether students who received GeoGebra-assisted instruction achieved higher learning outcomes than those taught through traditional methods. It tested hypotheses that compared achievement differences between the two groups.

Research question

What was the effect of GeoGebra-assisted instruction on grade 11 students' achievement in measurement at a selected secondary school in Guyana?

Hypotheses

The study evaluated whether the instructional approach influenced students' performance in measurement. It compared outcomes from GeoGebra-assisted lessons with those from traditional teaching methods. These comparisons formed the basis for the following hypotheses.

Null Hypothesis

There was no statistically significant difference in measurement achievement scores between Grade 11 students who received GeoGebra-assisted instruction and those who received traditional instruction.

$$H_0: \mu_1 = \mu_2$$

Alternative Hypothesis

There was a statistically significant difference in measurement achievement scores between Grade 11 students who received GeoGebra-assisted instruction and those who received traditional instruction.

$$H_1: \mu_1 \neq \mu_2$$

Significance of the Study

Contribution to Student Achievement and Educational Equity

This research directly addressed persistent underachievement in CSEC Mathematics measurement concepts that partially limits Guyanese students' access to tertiary education and STEM careers. The study provides educators with evidence suggesting that GeoGebra-assisted instruction may support improved learning outcomes at a critical instructional juncture where intervention is needed. GeoGebra's open-source nature eliminates licensing costs that prevent Guyana's schools from accessing educational software, making findings immediately actionable across socioeconomic contexts. Students in the school gained access to visualization tools previously available only in well-resourced institutions, potentially narrowing achievement gaps. This

democratization of educational technology aligns with regional development goals emphasizing inclusive and equitable quality education.

Influence on Pedagogical Practice and Teacher Development

This research provided empirical evidence that mathematics educators can use to justify departing from traditional methods that have proven ineffective. The study demonstrated whether GeoGebra produces measurable achievement gains in actual Guyanese classrooms. Teachers received not only evidence that GeoGebra works but also concrete guidance on integrating it effectively within existing curriculum structures, time constraints, and resource limitations. The study identified specific pedagogical competencies required for effective technology integration, informing pre-service and in-service teacher training programs. This research guided resource allocation toward training initiatives with demonstrated effectiveness rather than generic technology workshops lacking empirical foundation.

Impact on Educational Policy and Resource Allocation

This research provided policymakers with evidence-based justification for technology investments in mathematics education when administrators face pressure to improve achievement while managing limited budgets. The study enabled administrators to make informed decisions about purchasing devices, developing infrastructure, or licensing software by understanding which interventions produce measurable learning gains. Research demonstrating GeoGebra's effectiveness in teaching CSEC syllabus content. The study provided an empirical foundation for updating curriculum frameworks to reflect evidence-based best practices. This research models how educational systems can systematically assess technology initiatives before scaling them regionally, preventing wasteful investment in unproven interventions

Potential for Transformative Social Change

This study advanced social justice by improving educational outcomes for marginalized populations, as mathematics achievement strongly predicts socioeconomic mobility throughout the Caribbean. Students from disadvantaged backgrounds who master mathematics gain pathways out of poverty through tertiary education, vocations, and professional careers. The research empowered teachers as agents of educational improvement by involving local educators in research design, implementation, and dissemination, validating their professional knowledge. Mathematical literacy will enable informed citizenship, critical thinking about quantitative information, and participation in democratic processes requiring numerical reasoning. Students who develop strong mathematical foundations engage more effectively with public health information, environmental data, economic policy debates, and other civic domains where quantitative literacy matters.

Research direction significance

This research formed a baseline of empirical data on the effectiveness of GeoGebra in the selected secondary school mathematics programme. Filling this gap was crucial and was used to conduct subsequent comparative research across the secondary schools in Mahaica-Berbice, Guyana. The study illustrated the rigor of quasi-experimental design that suits the environment where randomization is not applicable to other studies offering methodological designs to scholars exploring GeoGebra interventions in resource-limited settings. The study also recognized the particular variables that should be further researched through a follow-up study by recording implementation processes, technological challenges, and effects of transfers. Future research on the varied effects on different areas of mathematics, the ideal period of implementation and the minimum infrastructure needed were informed by the baseline data. The study acted as an impetus to long-term scholarly investigation that helped national scholars to develop cumulative knowledge regarding how to integrate technology in a culturally responsive manner.

Theoretical significance

Theoretically, this study contributed to the scholarly literature by examining the applicability of Constructivism, Technological Pedagogical Content Knowledge (TPACK), and Cognitive Load Theory within

a resource-constrained Caribbean secondary school context. Existing theoretical applications of these frameworks have been predominantly grounded in data from well-resourced, developed-nation educational settings. By situating the investigation within a Guyanese school, this study extended the contextual reach of these frameworks and generated evidence that either supported or qualified their predictive value in non-Western, resource-limited environments.

Review of Related Literature

Grade 11 students at the selected secondary school consistently demonstrated unsatisfactory achievement in measurement concepts, particularly in identifying properties and calculating surface area and volume of right solids. Traditional instruction relied heavily on textbook examples, static diagrams, and rote memorization that failed to develop the conceptual understanding necessary for success on Caribbean Secondary Education Certificate (CSEC) Mathematics examinations. The purpose of this quantitative quasi-experimental study is to determine the effect of GeoGebra-assisted instruction on Grade 11 students' achievement in measurement concepts at a selected secondary school in Guyana. This study compared the measurement achievement outcomes of students receiving GeoGebra-assisted instruction with those receiving traditional instruction over a 4-week period.

This section synthesized existing research relevant to GeoGebra-assisted instruction in mathematics education and established the theoretical foundation for investigating technology integration in measurement teaching. The review began with a detailed description of the literature review search strategy that guided the identification and selection of relevant studies. The theoretical framework section examined three interconnected perspectives. These were constructivism, Technological Pedagogical Content Knowledge (TPACK), and Cognitive Load Theory. The same collectively explained how GeoGebra-assisted instruction may enhance measurement achievement. The literature review analysed research on GeoGebra's utility in measurement instruction, examined the strengths and limitations of the software in mathematics curricula, investigated factors influencing measurement achievement in secondary schools, explored CSEC Mathematics performance trends specific to measurement concepts, and identified conceptual misunderstandings that impede student success in surface area and volume calculations. The chapter concluded by documenting the substantial knowledge gap regarding GeoGebra implementation in Caribbean and Latin American educational contexts, highlighting the critical need for regionally situated research that addresses the unique challenges facing CARICOM nations.

Literature review search strategy

This literature review employed a systematic approach to identify and synthesize relevant research on GeoGebra-assisted instruction in mathematics education, with particular emphasis on measurement concepts in secondary schools. The researcher conducted comprehensive searches across multiple academic databases including ERIC, Google Scholar, ProQuest Education Database, Springer, and Taylor & Francis using Boolean operators to combine key terms such as 'GeoGebra AND mathematics achievement' and 'measurement instruction AND technology integration.' Initial searches identified approximately 90 potentially relevant articles based on title and abstract screening, which the researcher narrowed to 85 studies through detailed full-text evaluation using explicit inclusion criteria. Studies qualified for inclusion if they examined dynamic geometry software in secondary mathematics contexts and investigated measurement concepts through rigorous quantitative, qualitative, or mixed-methods research designs. The researcher organized included studies thematically according to their contributions to understanding GeoGebra's utility in measurement instruction, factors influencing achievement, and pedagogical implementation challenges. Targeted searches for Caribbean and Latin American literature revealed substantial gaps in regionally situated research, highlighting the need for investigations within CARICOM educational contexts. This systematic search strategy established a rigorous foundation for synthesizing existing knowledge while identifying critical research gaps that this investigation addressed.

Theoretical framework

This study examined GeoGebra-assisted instruction through three interconnected theoretical lenses. These frameworks were constructivism, Technological Pedagogical Content Knowledge (TPACK) and Cognitive Load Theory. These theoretical perspectives collectively explained the pedagogical pathways through which GeoGebra-assisted instruction could potentially enhance students' measurement achievement.

Constructivism

Constructivism postulates that learners actively construct knowledge through experiences rather than passively absorbing information transmitted by teachers (Shittu & Alex, 2025). Students develop deeper conceptual understanding when they participate in learning activities that require active manipulation of mathematical objects and reflection on emerging patterns (Akendita et al., 2024). GeoGebra epitomizes constructivist principles by transforming abstract measurement concepts into manipulable digital objects that students can explore dynamically. Students construct meaning about volume and surface area by manipulating virtual prisms and observing how dimensional changes affect measurements in real-time (Mozahem et al., 2021). The software environment encourages experimentation without fear of permanent errors, fostering a constructivist mindset where mistakes become learning opportunities rather than failures. Teachers facilitate learning by designing tasks that guide students through their zone of proximal development, providing scaffolding that bridges current understanding and target competencies (Attard & Holmes, 2020). GeoGebra supports this scaffolded exploration by offering immediate visual feedback that helps students evaluate their mathematical thinking and adjust their strategies.

Technological Pedagogical Content Knowledge (TPACK)

The TPACK framework conceptualizes effective technology integration as requiring the synthesis of three distinct knowledge domains that educators must coordinate simultaneously. Technological knowledge encompasses understanding of digital tools and their capabilities (Li et al., 2024). Pedagogical knowledge includes expertise in teaching methods and learning theories. Content knowledge comprises deep understanding of subject matter concepts and common student misconceptions (Deng et al., 2020). The framework argues that these domains must integrate into a cohesive understanding that transcends their individual components.

Teachers implementing GeoGebra for measurement instruction must develop technological knowledge of the software's interface and dynamic linking capabilities, pedagogical knowledge to design constructivist activities and facilitate student exploration, and content knowledge to identify which measurement concepts GeoGebra can illuminate effectively (Galanti et al., 2020). Research confirms that teachers with well-developed TPACK implement technology more effectively and produce better student outcomes than teachers with strong technological skills but weak pedagogical or content knowledge (Bulut & Isiksal-Bostan, 2019). Mathematics teachers who possess robust TPACK demonstrate greater confidence in integrating dynamic geometry software and design more pedagogically sound technology-enhanced lessons (Bretscher, 2022).

Cognitive Load Theory

Cognitive Load Theory explains how the architecture of human cognition constrains learning and provides principles for designing instruction that optimizes cognitive processing. The theory distinguishes three types of cognitive load that compete for limited working memory resources during learning (Sweller et al., 2019). Intrinsic cognitive load arises from the inherent complexity of the material itself. Extraneous cognitive load results from instructional design choices that impose unnecessary processing demands unrelated to learning objectives. Germane cognitive load reflects the cognitive effort devoted to schema construction and automation, which produces lasting learning (Barbieri & Rodrigues, 2025).

Measurement concepts in three-dimensional geometry impose substantial intrinsic cognitive load because students must simultaneously coordinate spatial visualization, dimensional relationships, formula structures, and numerical calculations (Castro-Alonso et al., 2019). Traditional instruction often amplifies extraneous

cognitive load by presenting static two-dimensional diagrams that require students to mentally construct three-dimensional objects while simultaneously processing verbal explanations and symbolic formulas (Castro-Alonso et al., 2019). This split-attention effect forces students to mentally integrate information sources, consuming working memory capacity that could otherwise support schema construction. The software reduces extraneous cognitive load by spatially integrating visual representations with algebraic expressions and numerical values, eliminating split-attention effects that plague traditional textbook presentations ((Barbieri & Rodrigues, 2025). Dynamic visualizations reduce intrinsic cognitive load by allowing students to explore complex three-dimensional relationships incrementally rather than processing all elements simultaneously (Castro-Alonso et al., 2019).

Framework integration

These three theoretical frameworks provide complementary explanations for how GeoGebra-assisted instruction may enhance measurement achievement. Constructivism describes the epistemological mechanism through which students develop mathematical understanding by actively manipulating representations and discovering relationships through exploration. The TPACK framework specifies the teacher knowledge requirements necessary for designing and implementing effective technology-enhanced instruction that balances technological capabilities with pedagogical strategies and content goals. Cognitive Load Theory identifies the cognitive mechanisms through which GeoGebra's design features optimize learning by managing working memory demands and focusing cognitive resources on schema construction.

LITERATURE REVIEW OF KEY CONCEPTS AND VARIABLES

Studies on the Utility of GeoGebra in Measurement

Researchers have conducted extensive quantitative studies examining GeoGebra's impact on geometry learning outcomes in recent years. Carriazo-Regino et al. (2024) implemented a quasi-experiment with tenth grade students, which revealed that students who received GeoGebra-assisted instruction achieved significantly higher scores in trigonometric competency compared to their peers in traditional instruction groups. Zulnaldi and Oktavika (2020) conducted a quantitative experimental study with Greek secondary students, demonstrating that GeoGebra integration enhanced student performance in three-dimensional geometry tasks involving spatial reasoning and visualization. Fitri et al. (2020) employed a quantitative pre-test post-test design with 72 Indonesian junior high school students, finding that GeoGebra significantly improved achievement in geometry topics including angles, triangles, and quadrilaterals.

Furthermore, A study revealed that GeoGebra not only improved geometry knowledge but also increased student engagement and reduced anxiety (Gurmu et al., 2024; Prince, 2024). Additionally, Ismail and Rahman (2017) conducted a mixed-methods study with Turkish middle school students examining learning trajectories in geometry, finding through both quantitative assessments and qualitative observations that GeoGebra enhanced conceptual understanding of geometric properties through dynamic manipulation. Asnawi et al. (2023) implemented a mixed-methods design with Greek primary school students, discovering through statistical analysis and classroom observations that GeoGebra facilitated deeper connections between concrete manipulations and abstract geometric concepts in measurement tasks.

Qualitative studies have explored the pedagogical mechanisms underlying GeoGebra's effectiveness in geometry instruction. Kandaga et al. (2024) conducted a qualitative case study examining how secondary teachers integrated GeoGebra into geometry lessons, revealing that successful implementation required substantial pedagogical redesign rather than simple substitution of traditional methods. Dogruer and Akyuz (2020) performed qualitative classroom observations in Turkey, finding that GeoGebra enabled students to explore geometric relationships through experimentation and conjecture-testing rather than memorization of formulas. Kutluca (2013) used qualitative analysis of student discourse during GeoGebra activities, documenting how the software transformed problem-solving approaches by enabling real-time manipulation of geometric objects and immediate feedback on mathematical conjectures.

Research specific to measurement concepts has demonstrated GeoGebra's utility in developing spatial reasoning and measurement sense. Lindenbauer and Lavicza (2021) conducted a quantitative study with Brazilian students investigating area and perimeter understanding, revealing that dynamic manipulation of shapes in GeoGebra helped students grasp conservation principles more effectively than static representations. Noviana et al., (2020) implemented a quantitative experimental design with secondary students examining volume concepts, finding that GeoGebra-assisted instruction significantly reduced common misconceptions about three-dimensional measurement. Jelatu et al. (2018) employed a quasi-experimental quantitative approach with Indonesian vocational students, demonstrating through achievement tests that GeoGebra enhanced understanding of geometric measurement including perimeter, area, surface area, and volume calculations.

Strengths and Limitations of GeoGebra in Mathematics Curricula

GeoGebra offers several pedagogical strengths that distinguish it from traditional instructional methods. The software provides dynamic linking between algebraic equations and geometric representations, enabling students to manipulate objects and observe immediate changes across multiple representations simultaneously (Cockett & Kilgour, 2015). Researchers have documented that this multi-representational capability supports conceptual understanding by helping students forge connections between symbolic, visual, and numerical forms of mathematical concepts. The platform offers scaffolding through construction tools that guide students toward valid geometric relationships while maintaining mathematical rigor (Dogruer & Akyuz, 2020). GeoGebra's free and open-source nature eliminates cost barriers that often prevent schools from adopting educational technology, making it accessible to resource-constrained educational contexts. The extensive online repository of pre-constructed materials allows teachers to access thousands of ready-made activities, reducing preparation time and providing pedagogical models for effective implementation (Simanjuntak et al., 2021; Wassie & Zergaw, 2019).

The software supports differentiated instruction by allowing teachers to create activities at varying complexity levels that accommodate diverse learner needs (Vennila et al., 2023). GeoGebra facilitates mathematical exploration and discovery learning by enabling students to test conjectures through direct manipulation rather than relying solely on procedural memorization (Cockett & Kilgour, 2015; Vennila et al., 2023). The platform's augmented reality features, introduced in recent versions, extend geometric exploration into three-dimensional physical spaces, enhancing spatial reasoning development (Kandaga et al., 2024). GeoGebra supports formative assessment through built-in feedback mechanisms that help teachers monitor student understanding in real-time during technology-based activities (Wassie & Zergaw, 2019).

However, researchers have identified significant limitations that constrain GeoGebra's effectiveness in practice. The software requires substantial technological literacy from both teachers and students, creating initial barriers to adoption that many educators find overwhelming (Wassie & Zergaw, 2019). Teachers report that effective GeoGebra integration demands extensive preparation time to design appropriate activities, learn the software interface, and anticipate student difficulties that may arise during implementation (Gurmu et al., 2024). The emphasis on exploration and discovery can lead to inefficient use of instructional time if teachers lack clear learning objectives or fail to provide adequate structure and guidance (Dogruer & Akyuz, 2020). Technical difficulties including software crashes, compatibility issues, and inadequate hardware infrastructure frequently disrupt lessons and frustrate both teachers and students across various educational contexts (Jelatu et al., 2018).

Researchers have cautioned that overreliance on dynamic visualizations may prevent students from developing abstract reasoning skills necessary for higher-level mathematics (Lindenbauer & Lavicza, 2021). Students may struggle to transfer knowledge gained through GeoGebra manipulation to traditional paper-and-pencil assessments that remain standard in most educational systems (Ntshangase et al., 2024). The cognitive load associated with learning both mathematical concepts and software navigation simultaneously can overwhelm some students, particularly those with limited prior technology experience (Fitri et al., 2020). The lack of structured professional development programs means that many teachers implement GeoGebra ineffectively, using it merely as a demonstration tool rather than leveraging its full pedagogical potential (Dogruer & Akyuz, 2020).

Mathematics Measurement Achievement in Secondary Schools

The measurement strand presents unique cognitive challenges that distinguish it from other mathematical domains. Measurement concepts require students to coordinate multiple representational systems simultaneously, including two-dimensional drawings, three-dimensional objects, numerical calculations, and spatial reasoning (Sisman & Aksu, 2015). Students must transition between concrete physical manipulation and abstract mathematical formalization, a cognitive leap that many adolescents find demanding (Huang & Witz, 2012). The measurement domain demands robust spatial visualization abilities that enable learners to mentally manipulate geometric objects, recognize properties from different perspectives, and understand how two-dimensional representations correspond to three-dimensional reality (Gómez-García et al., 2020).

Measurement tasks inherently involve approximation and uncertainty rather than the exact answers characteristic of arithmetic and algebra, creating conceptual discomfort for students accustomed to precise solutions (Ismail & Rahman, 2017). The multiplicative reasoning required for area and volume calculations differs fundamentally from the additive thinking that dominates early mathematics education, forcing students to restructure their mathematical understanding (Huang, 2016). Students struggle to distinguish between linear, quadratic, and cubic relationships when calculating perimeter, area, and volume respectively, often applying inappropriate dimensional reasoning to measurement problems (Izard, 2020). The contextual nature of measurement means that students must interpret real-world situations, make appropriate unit selections, and evaluate the reasonableness of solutions rather than simply executing algorithms (Asnawi et al., 2023).

The abstraction level increases substantially as students' progress from measuring length to calculating area and volume, with each dimensional increase adding layers of complexity (Huang & Witz, 2012). Many measurement concepts violate students' intuitive conceptions about physical space, such as the independence of area and perimeter or the non-conservation of volume during shape transformations (Sisman & Aksu, 2015). The procedural emphasis in traditional mathematics instruction leaves students able to apply formulas mechanically without understanding the underlying geometric principles that justify those procedures (Izard, 2020). Students encounter difficulty coordinating unit iteration with formula application, failing to recognize that formulas represent systematic counting of measurement units (Asnawi et al., 2023).

Caribbean Secondary Education Certificate (CSEC) Measurement performance trends

The Caribbean Examinations Council has documented persistently unsatisfactory performance in measurement topics across recent examination cycles. Analyses of CSEC Mathematics performance data from 2018 to 2023 revealed that measurement questions consistently ranked among the lowest-scoring items on the general proficiency papers (Caribbean Examinations Council, 2023). The regional examination reports indicated that fewer than 40% of candidates demonstrated adequate competency in three-dimensional geometry and measurement applications, representing a significant achievement gap compared to other mathematical strands (Joseph & Turner, 2025). Caribbean students showed particular weakness in problems requiring visualization of three-dimensional objects from two-dimensional representations, with success rates on such questions frequently falling below 30% (Caribbean Examinations Council, 2022).

The examination reports highlighted that candidate struggled disproportionately with surface area calculations involving composite solids, with the majority of students unable to unpack complex shapes into manageable components (Caribbean Examinations Council, 2021). Volume problems involving non-standard units or requiring unit conversions produced especially poor performance, suggesting that students lack conceptual understanding of volume as space-filling (Caribbean Examinations Council, 2023). The trend data indicated no substantial improvement in measurement achievement over the five-year period despite curricular reforms intended to strengthen geometric and spatial reasoning (Lewis, 2023). Problems requiring application of the Pythagorean theorem in three-dimensional contexts revealed fundamental gaps in students' ability to identify right triangles within complex geometric configurations (Caribbean Examinations Council, 2022).

The examination reports noted that candidates frequently confused formulas for different geometric solids, applying cylinder volume formulas to cones or miscalculating surface areas by omitting faces (Caribbean Examinations Council, 2021). Questions assessing understanding of scale factors in similar figures showed



that students struggled to apply appropriate dimensional scaling, often using linear scale factors for area and volume calculations (Caribbean Examinations Council, 2023). The regional performance patterns indicated that measurement weaknesses persist from lower secondary through upper secondary levels, suggesting that foundational conceptual gaps accumulate rather than resolve over time (Lewis, 2023).

Conceptual Misunderstandings in Surface Area, Volume, and Properties of Solids

Students harbour robust misconceptions about surface area that persist despite instruction. Many learners believe that surface area and volume maintain a fixed relationship, expecting that doubling linear dimensions will double both surface area and volume (Sisman & Aksu, 2015). Students frequently count only visible faces when calculating surface area from diagrams, failing to recognize that three-dimensional objects have hidden surfaces that must be included in total surface area calculations (Lewis, 2023). The distinction between lateral surface area and total surface area remains unclear for many students, who apply formulas inconsistently or create hybrid procedures combining elements of both calculations (Lewis, 2023; McDonald, 2025).

Students demonstrate fundamental misunderstandings about volume as a measure of three-dimensional space. Many learners conceive of volume as the sum of dimensions rather than their product, adding length, width, and height instead of multiplying them (Huang & Witz, 2012). The relationship between volume and capacity confuses students, who struggle to connect abstract cubic units with practical liquid measurement contexts (Jelatu et al., 2018). Students often fail to recognize that objects with identical volumes can have vastly different surface areas, revealing incomplete understanding of the independence of these measurement attributes (Jelatu et al., 2018). The concept of volume conservation remains fragile, with students believing that pouring liquid into differently shaped containers changes the total volume (Lewis, 2023).

Misconceptions about properties of geometric solids impede measurement achievement. Students incorrectly believe that all pyramids have square bases or that cones represent a distinct category unrelated to pyramids (Fujita et al., 2020). Many learners struggle to identify edges, faces, and vertices consistently, particularly for solids with curved surfaces where the definitions become less straightforward (Carneiro & Barbosa, 2021). Students demonstrate confusion about the relationship between prisms and cylinders, viewing them as completely separate categories rather than recognizing cylinders as circular prisms (Cockett & Kilgour, 2015). The concept of a net as an unfolded representation of a three-dimensional solid challenges students, who cannot mentally fold two-dimensional patterns into corresponding solids or vice versa (Leacock, 2015).

Students exhibit misconceptions about geometric properties that affect measurement calculations. Many learners believe that rectangular prisms must have square faces or that the base of a solid must be the bottom face in a particular orientation (Wassie & Zergaw, 2019). Students struggle to identify congruent and similar figures within three-dimensional contexts, failing to recognize when faces of compound solids share dimensions (Fujita et al., 2020). The distinction between surface area of individual faces and total surface area remains conceptually unclear, with students treating these as interchangeable concepts (Sisman & Aksu, 2015). Students demonstrate weak understanding of how geometric transformations affect measurements, incorrectly predicting measurement changes under rotations, reflections, and translations (Carneiro & Barbosa, 2021).

Challenges in Teaching Measurement Utilizing Traditional Approaches

Traditional measurement instruction emphasizes formula memorization and procedural execution at the expense of conceptual development. Teachers typically present measurement formulas as arbitrary rules to be memorized rather than as logical consequences of geometric principles, leaving students without conceptual anchors for formula application (Cockett & Kilgour, 2015). The instructional sequence in conventional classrooms moves too quickly from concrete manipulation to abstract symbolism, failing to provide adequate experiences at intermediate representational levels (Cockett & Kilgour, 2015). Teachers demonstrate measurement procedures using two-dimensional diagrams without sufficient attention to developing three-dimensional visualization skills that students need for independent problem-solving (Gomez-Garcia et al., 2020).

The traditional approach to measurement instruction relies heavily on worked examples and imitation rather than exploration and discovery. Teachers model solution procedures step-by-step, expecting students to replicate these procedures on similar problems without necessarily understanding the underlying mathematical reasoning (Huang, 2016). This instructional pattern produces students who can calculate measurements when problems match practiced templates but fail when faced with novel configurations or non-routine applications (Wassie & Zergaw, 2019). The emphasis on speed and efficiency in traditional instruction discourages the reflective thinking necessary for developing robust measurement concepts. Traditional measurement pedagogy fails to address the spatial reasoning demands inherent in three-dimensional geometry. Teachers provide limited opportunities for students to manipulate physical models, build geometric solids, or engage in hands-on measurement activities that would support conceptual understanding (Carneiro & Barbosa, 2021). The instructional focus on symbolic manipulation means that students rarely experience measurement as a practical activity involving real objects and actual measurements (Sisman & Aksu, 2015). Teachers present measurement formulas for various geometric solids in rapid succession without helping students recognize structural relationships among formulas or understand why similar shapes require similar calculation approaches (Leacock, 2015).

Assessment practices in traditional classrooms reinforce procedural rather than conceptual understanding. Tests typically feature straightforward problems requiring direct formula application with clearly labelled dimensions, failing to assess whether students understand measurement principles (Mozahem et al., 2021). The absence of questions requiring spatial reasoning, visualization, or application to real-world contexts means that students can achieve passing grades without developing genuine measurement competence (Fujita et al., 2020). Teachers rarely use formative assessment to identify and address specific misconceptions, instead moving forward with new content regardless of student understanding levels (Huang & Witz, 2012).

Factors that influence measurement achievement

Visualization ability directly impacts students' achievement by determining how effectively they can interpret diagrams and imaging three-dimensional structures. Students who can mentally manipulate 2D and 3D shapes, rotate them to examine their properties, and unpack complex solids into simpler components demonstrate significantly higher competency (Carriazo-Regino et al., 2024). The capacity to visualize cross-sections and understand how two-dimensional slices relate to three-dimensional objects predicts success on volume and surface area problems (Lowrie et al., 2017). Students with weak visualization skills struggle to connect two-dimensional nets with three-dimensional solids, impeding their ability to calculate surface area systematically (Carriazo-Regino et al., 2024). The ability to imagine hidden faces and edges that are not visible in diagrams separates high-performing students from those who can only process explicitly shown information (Newcombe & Frick, 2010).

Formula application proficiency influences measurement achievement, though the nature of this influence depends on whether students possess conceptual understanding alongside procedural knowledge. Students who understand formulas as expressions of geometric relationships and spatial patterns apply them more flexibly and accurately than those who treat formulas as arbitrary symbol manipulations (Fitri et al., 2020). The ability to identify which formula applies to a particular geometric configuration requires spatial reasoning combined with categorical knowledge about geometric objects (Sisman & Aksu, 2015). Students who can adapt standard formulas for non-standard situations or combine formulas to solve complex measurement problems demonstrate deeper understanding than those who can only execute memorized procedures (Huang, 2016). Formula retrieval failures occur frequently among students who learned formulas through memorization without conceptual grounding, as they lack the geometric understanding that would allow formula reconstruction (Zulnaidi & Oktavika, 2020).

Misconceptions actively interfere with measurement achievement by causing students to apply incorrect reasoning even when they possess relevant knowledge. The misconception that perimeter and area maintain fixed relationships leads students to make false predictions about how shape changes affect measurements (Huang & Witz, 2012). Students who believe that all geometric formulas follow additive patterns struggle with the multiplicative structure of area and volume calculations (Ismail & Rahman, 2017). The misconception that larger objects always have greater surface area-to-volume ratios prevents students from understanding scaling

relationships in geometry (Mozahem et al., 2021). Students who view formulas as separate, unrelated procedures fail to recognize structural similarities that could support learning and memory (Sisman & Aksu, 2015).

Prior knowledge and experience with spatial activities predict measurement achievement across educational levels. Students who have extensive experience building with blocks, solving puzzles, reading maps, and engaging in other spatial activities develop stronger measurement understanding (Mix et al., 2016). The amount and quality of prior geometry instruction influence measurement performance, with students who have conceptual geometry foundations outperforming those whose prior instruction emphasized only procedural skills (Wassie & Zergaw, 2019). Cultural and experiential factors shape students' familiarity with measurement contexts, affecting their ability to interpret problems and evaluate solutions (Newcombe & Frick, 2010). Students from environments with limited access to manipulatives, construction activities, and hands-on measurement experiences enter secondary mathematics with weaker spatial foundations (Lowrie et al., 2017).

Cognitive load theory provides a framework for understanding why measurement tasks overwhelm many students and how instruction can reduce unnecessary cognitive demands. The theory distinguishes between intrinsic load inherent in measurement concepts, extraneous load from poor instructional design, and germane load that supports learning (Leacock, 2015). Effective measurement instruction minimizes extraneous load through clear representations and well-structured examples while managing intrinsic load through appropriate sequencing and scaffolding (Huang, 2016). The framework suggests that worked examples, graduated problem sequences, and integrated visual-verbal presentations can reduce cognitive load and improve measurement learning (Huang & Witz, 2012).

Knowledge Gap in the Caribbean Community (CARICOM) and Latin America

Caribbean educational contexts remained significantly underrepresented in the GeoGebra research literature, creating substantial gaps in understanding how the software functions in small island developing states. No published studies had systematically examined GeoGebra implementation in Guyana or other CARICOM nations despite their unique educational challenges and cultural contexts. The limited research from Caribbean contexts suggested that findings from North American, European, and Asian studies may not transfer directly to regional settings characterized by different curriculum structures, assessment systems, and educational priorities (Sweeney & George, 2024). Researchers had not investigated how GeoGebra's pedagogical affordances align with the competency-based curriculum frameworks increasingly adopted across Caribbean education systems. The interaction between GeoGebra use and preparation for high-stakes regional examinations such as the Caribbean Secondary Education Certificate remains unexplored, leaving teachers uncertain about how technology integration affects examination performance (Sweeney et al., 2024).

Studies examining GeoGebra implementation in resource-constrained environments had focused primarily on sub-Saharan Africa and rural Asia, neglecting the specific constellation of challenges facing Caribbean nations. The literature lacked investigation into how Caribbean teachers adapt GeoGebra activities when faced with unreliable electricity, limited internet connectivity, and shared computer access rather than one-to-one device ratios (Leacock, 2015). No research had examined whether GeoGebra materials developed in Western contexts require cultural adaptation to reflect Caribbean students' experiences, linguistic patterns, or mathematical application contexts. The literature did not address how Caribbean teachers without access to formal technology training programs acquire the pedagogical and technical knowledge necessary for effective GeoGebra integration (McDonald, 2025).

The research base lacked studies examining GeoGebra's effectiveness specifically within Caribbean multilingual contexts where students often navigate between Creole languages and Standard English during mathematics instruction (Sweeney et al., 2024). No investigations had explored how GeoGebra implementation interacts with the socioeconomic disparities prevalent across Caribbean educational systems, where urban schools may have technology access while rural and interior schools operate with minimal resources. The literature provided no guidance on sustainable models for GeoGebra integration that account for high teacher turnover rates, limited technical support infrastructure, and competing curricular demands characteristic of Caribbean school systems (Sweeney & George, 2024).

METHODOLOGY

Research design

The independent variable was the instructional method with two levels: GeoGebra-assisted instruction and traditional instruction. The dependent variable was student achievement in measurement measured by scores on the Measurement Achievement Test. Confounding variables included but were not limited to prior knowledge, student motivation, teacher effects, and external support factors.

This study employed a quantitative quasi-experimental design, specifically the Non-Equivalent Pre-test-Post-test Control Group Design. This design was appropriate because it allows investigation of cause-and-effect relationships between instructional methods and student achievement while accommodating the practical constraints of educational settings where random assignment is not feasible (Creswell & Creswell, 2018). The design involved two intact Grade 11 classes at the selected secondary school in Guyana. One class was designated as the experimental group receiving GeoGebra-assisted instruction, while the other served as the control group receiving traditional instruction. Both groups completed identical pre-tests before the intervention, received four weeks of instruction on measurement concepts, and completed identical post-tests after the intervention period.

Table 1 Shows Non-Equivalent Pre-test-Post-test Control Group Design.

Group	Pre-test	Treatment	Post-test
Experimental	O ₁	X	O ₂
Control	O ₁	—	O ₂

Note. O₁ = pre-test; X = GeoGebra-assisted instruction and O₂ = post-test;

This design addressed the research question by comparing measurement achievement between groups that differed only in instructional approach. The pre-test established baseline equivalence, the intervention provided the independent variable manipulation, and the post-test measured treatment effects on the dependent variable.

Research method

Population and Sampling Strategy

Target population

The population for this study comprised 94 Grade 11 students enrolled at the selected secondary school in Mahaica-Berbice, Guyana. These students maintained an average age of 16 years and 4 months. The cohort comprised 40 males and 54 females distributed across three intact classes. The classes were Business, Humanities and Science Streams. The school served a semi-rural community characterized by adequate resources which included computer access with internet connectivity, and updated textbooks aligned with current syllabi. The demographic profile of this institution mirrored many secondary schools throughout Guyana's coastal regions. The students came from predominantly working-class families engaged in agriculture, small business enterprises, and service sector employment. These students faced the immediate pressure of preparing for Caribbean Secondary Education Certificate (CSEC) Mathematics examinations, which determine their educational and career trajectories upon completion of secondary school. Students who successfully complete CSEC Mathematics gain access to tertiary education opportunities and employment, while those who struggle face limited post-secondary options that constrain their socioeconomic mobility (Sweeney & George, 2024).

Sampling technique

This study employed cluster sampling. A probability sampling technique in which naturally occurring groups serve as sampling units rather than individual students (Ary et al., 2019). The researcher selected this approach because it addressed both practical constraints and methodological considerations inherent in educational research settings. Random assignment of students to experimental and control groups would have interrupted intact classes. These structures were carefully organized based on students' prospective career choice, administrative, pedagogical, and logistical considerations. School administrators cannot feasibly re-organize entire grade levels to accommodate research requirements without causing significant disruption to ongoing educational programs (Creswell & Creswell, 2018). The cluster sampling approach preserved intact classes, which maintained the natural educational environment that students and teachers have established throughout the academic year.

Cluster sampling enhanced the validity of the research by allowing the study to occur within authentic classroom contexts rather than artificial experimental settings. Students learned within their established peer groups where they have developed social relationships, communication patterns, and collaborative working arrangements that influence their educational experiences. Teachers worked with familiar groups of students whose individual learning needs, behavioral patterns, and academic capabilities they have come to understand through months of daily interaction. This naturalistic approach increased the likelihood that research findings will generalize to neighboring schools with similar academic performance in CSEC Mathematics. The sampling technique also minimized treatment contamination that could compromise the experimental design's integrity. Students who attended different class periods have limited opportunities to discuss lesson activities, share learning strategies, or exchange information about instructional approaches they experience. This separation reduced the probability that control group students will gain access to GeoGebra resources or learn about experimental group activities, which would blur the distinction between treatment conditions and undermine the study's ability to detect intervention effects. Teachers working with distinct intact classes could maintain treatment fidelity more effectively than if students from different conditions interacted regularly throughout the school day.

Sampling procedure

The researcher randomly selected two intact classes from the three available Grade 11 classes to participate in the study. This selection process ensured that each class has an equal probability of inclusion, thereby preventing researcher bias in sample formation. The researcher assigned each of the three classes a numerical identifier from one to three. Three identical pieces of paper, each marked with one of these numbers, were folded uniformly and placed in an opaque container. The researcher shook the container thoroughly to mix the papers, then drew two papers without replacement while blindfolded to ensure unbiased selection. The two classes corresponding to the drawn numbers constituted the study sample. The researcher randomly assigned the two selected classes to experimental or control conditions through a coin toss procedure. Each class was arbitrarily designated as either 'heads' or 'tails' before the coin toss occurred. The researcher tossed a fair coin once, and the outcome determined which class received GeoGebra-assisted instruction as the experimental group and which class received traditional instruction as the control group. This randomization eliminated systematic bias in condition assignment and helped ensure that any unknown confounding variables were distributed equally across groups through random assignment.

Sample size

The sample consisted of 62 students distributed across two intact classes, with each class containing 31 students. The researcher determined this sample size based on: statistical power, practical feasibility, and educational research norms. Statistical power analysis indicated that this sample size provided adequate power to detect small to medium effect sizes when using independent samples t-tests with conventional alpha levels. Cohen's power tables suggested that samples of 29 to 31 participants per group achieve power of approximately 0.50 to detect effect sizes of $d = 0.50$ or larger at $\alpha = .05$ for two-tailed tests. Educational interventions that produce practically meaningful improvements in student achievement typically generate effect sizes in the medium to large range, making this sample size appropriate for detecting educationally

significant differences. The selected secondary school typically organized Grade 11 mathematics classes with 25 to 35 students per stream, making individual class sizes with an average of 27 students, a representative of standard practice. The researcher could not substantially increase sample size without including additional classes, which would require more complex analytical approaches to account for classroom clustering effects and would demand additional resources for teacher training, instructional materials, and implementation monitoring. The two-class design balanced the competing demands of statistical adequacy and research feasibility within the constraints of a thesis project conducted in a developing nation context.

Data gathering procedures

Pre-test administration

The researcher administered the pre-test (Measurement Achievement Test) to both the experimental and control groups during their regular mathematics class periods on the same day, prior to the commencement of the instructional intervention. Both groups received identical written and verbal instructions, the same 90-minute time allocation, and completed the assessment under standard examination conditions. The co-investigator collected all completed scripts, secured them, and independently scored them using the standardised marking scheme (Appendix J) before instruction commenced, thereby ensuring that pre-test performance neither informed instructional planning nor introduced differential treatment expectations.

Intervention procedures

The four-week instructional intervention commenced in the week immediately following pre-test administration. A trained classroom teacher, who had received orientation on the software and lesson protocols prior to the study, delivered GeoGebra-assisted instruction to the experimental group through twelve structured lesson plans (Appendix M) in the school's computer laboratory. A second trained teacher delivered traditional instruction to the control group in the standard classroom setting, incorporating chalkboard demonstrations, textbook-based worked examples, and paper-based practice exercises. Both groups received instruction on identical CSEC-aligned measurement content covering properties of two-dimensional and three-dimensional shapes, surface area, and volume of right solids across the same number of instructional periods per week. The co-investigator conducted periodic classroom observations and cross-referenced lesson delivery against the prepared lesson plans to monitor and maintain treatment fidelity throughout the four-week period.

Post-test administration

The researcher administered the post-test (Measurement Achievement Test) to both groups simultaneously on the first scheduled mathematics class day following the conclusion of the four-week intervention. The same standardised conditions applied during pre-test administration. Both groups received identical instructions and the same 90-minute time allocation.

Instrumentation

The data collection instrument for this study was a researcher-developed Measurement Achievement Test consisting of 12 items aligned with CSEC Mathematics syllabus objectives for measurement. The test assessed measurement concepts through two sections that together provided comprehensive coverage of perimeter, area, total surface area, and volume. The first section contained 10 multiple-choice items that assessed students' ability to calculate perimeter, area, total surface area, and volume of two-dimensional and three-dimensional shapes following standard CSEC Mathematics examination format. The second section contained 2 problem-solving CSEC style questions that require students to apply measurement concepts to real-world contextual situations, with one item focusing on volume calculations and the other addressing total surface area calculations in extended response format. Each multiple-choice item earned one mark for correct responses, while each problem-solving question will earn marks based on a detailed marking rubric catering to procedures, appropriate formula selection, accurate calculations, and complete solutions with metric units. The test yielded a total possible score of 30 marks that provided adequate range for detecting individual differences and group comparisons. The researcher administered identical test formats as pre-test and post-test,

maintaining consistent structure, item types, and scoring procedures across both assessments to ensure valid measurement of achievement change.

Instrument Development and Validation

Instrument development process

A mathematics education specialist created a table of specifications (TOS) that mapped test items to specific CSEC learning objectives for measurement topics such as perimeter, area, surface area, and volume. A pool of 30 multiple-choice items and 6 problem-solving questions was created, drawing content from CXC-approved textbooks and past CSEC examination papers from 2015 to 2024. The multiple-choice items followed CSEC format with diagnostic distractors representing common student misconceptions. The problem-solving questions required multi-step solutions, formula identification, systematic calculations, and appropriate units to assess higher-order thinking skills (HOTS). A panel of three mathematics educators reviewed all items for content validity, clarity, and CSEC alignment. The mathematics specialist revised items based on panel feedback, resulting in a refined pool of 24 multiple-choice items and 4 problem-solving items.

The researcher conducted pilot testing with 30 Grade 11 students at a comparable secondary school to identify items with inappropriate difficulty and generate preliminary reliability estimates. The researcher calculated item difficulty indices and discrimination indices from pilot data, retaining items with difficulty indices between 0.30 and 0.80. Two independent markers scored all pilot responses using a detailed rubric, with Cohen's kappa coefficient quantifying inter-rater agreement. The researcher constructed two parallel test forms from the refined item pool, each containing 10 multiple-choice items and 2 problem-solving items matched for content coverage, difficulty level, and cognitive demand.

Validity evidence

The study established content validity through multiple complementary procedures. The table of specifications mapped test items to CSEC measurement learning objectives taken from the CSEC Mathematics syllabus. A panel of three qualified mathematics educators reviewed all items for content validity, clarity, and CSEC alignment. The educators verified alignment with CSEC mathematics syllabus, CXC approved textbooks and analysed past CSEC examination papers from 2015 to 2024. The researcher conducted an Item-Objective Congruence (IOC) analysis. The researcher evaluated the degree to which each test item matched its intended learning objective. IOC values provided numerical evidence of content-objective alignment. These values helped identify items requiring revision due to weak congruence.

The researcher demonstrated construct validity by designing items that require application of measurement principles to real-life contexts. Test items demanded multi-step reasoning and integration of concepts across measurement domains. The researcher examined pilot test data for positive correlations between test performance and teacher ratings of student mathematical ability. These correlations provided evidence that the test measured the intended mathematical construct. The researcher examined consequential validity through systematic pilot testing procedures. These procedures identified potential cultural bias, language barriers, and systematic disadvantages to particular student subgroups. The researcher disaggregated pilot test data by gender to detect differential item functioning. This analysis revealed whether items performed differently for male and female students with equivalent mathematical ability.

Reliability evidence

The researcher calculated internal consistency reliability using Cronbach's alpha coefficient based on pilot test data, with acceptable reliability indicated by alpha values of 0.70 or higher. A sub-sample of 20 pilot participants completed the same test form two weeks apart to assess test-retest reliability, with acceptable reliability indicated by Pearson correlation coefficients of 0.70 or higher. All 30 pilot participants completed both test forms on consecutive days under counterbalanced administration order to establish parallel forms reliability, with acceptable reliability indicated by correlation coefficients of 0.70 or higher. Two independent

markers scored all pilot test responses to problem-solving questions using the detailed marking rubric, with acceptable inter-rater reliability indicated by Cohen's kappa values of 0.70 or higher.

Data collection timeline

The data collection process occurred across six phases spanning 6 weeks. The researcher obtained IRB approval, selected school permission, and written parental consent during week one. The researcher conducted an onboarding session consisting of two hours of instruction for both experimental and control group teachers. The researcher administered the pre-test to both groups during week 1 using standardized procedures in 90-minute class periods. Both groups received four weeks of instruction on measurement concepts during weeks 2 through 5, with the experimental group using GeoGebra software for dynamic visualization and the control group receiving traditional instruction through direct explanation and practice. The researcher conducted weekly classroom observations and collected daily instructional logs from teachers throughout the intervention period. The researcher administered the immediate post-test during week 6. Two trained markers scored all assessments during week 6 and the researcher entered data into SPSS with verification procedures including double-entry of 20% of records.

Implementation fidelity measures

The two teachers received detailed standardized lesson plans for each of the 12 instructional sessions that specified learning objectives, instructional activities, materials, and formative assessment strategies. The lesson plans addressed identical measurement concepts in the same sequence but differed in pedagogical approach. The researcher conducted systematic classroom observations following a structured protocol that documented content accuracy, instructional strategies, student engagement levels, technology use, time allocation, and departures from prescribed procedures. The researcher observed two complete lessons per week for each group throughout the four-week intervention period. Teachers maintained daily instructional logs recording topics covered, activities completed, student understanding levels, technical difficulties, and deviations from lesson plans. The researcher administered a treatment differentiation check during week 5 by distributing a questionnaire to students asking them to describe typical classroom activities. The researcher analysed student responses using content analysis to verify that experimental group students described technology-based activities while control group students described traditional instruction, with successful differentiation indicated by at least 80% alignment.

Ethical considerations

This study was conducted in full accordance with the ethical standards established by the Institutional Review Board (IRB) of the University of the Southern Caribbean, which granted formal approval prior to any data collection activities (Appendix L). All participation in the study was entirely voluntary. The researcher obtained written informed consent from all student participants and from their parents or guardians prior to the commencement of the study, using a consent form that clearly outlined the study's purpose, procedures, potential benefits and risks, confidentiality protections, and the right to withdraw at any time without academic penalty (Appendix D). Participants' confidentiality and anonymity are protected. The researcher assigned each student a unique alphanumeric identification code EXP001 through EXP031 for the experimental group and CTRL001 through CTRL031 for the control group in place of names or other personal identifiers on all assessment materials and research documents.

The principal researcher and co-investigator stored all data in password-protected electronic files accessible exclusively to themselves. The study reports all findings in aggregate form, rendering individual identification impossible. The instructional intervention posed no foreseeable physical or psychological risk to participants, as both the GeoGebra-assisted and traditional instructional approaches aligned fully with the standard CSEC Mathematics curriculum and did not require students to engage in activities beyond the scope of their regular mathematics instruction. Both groups continued to receive complete, curriculum-aligned instruction throughout the study period, ensuring that participation did not disadvantage any student's examination preparation. The principal researcher will retain all research data for the period stipulated by institutional guidelines and will subsequently destroy them through secure means upon expiry of the retention period.

Acknowledgement of the Two-Teacher Design

The study assigned one trained teacher to each of the two intact classes, a decision that carried both practical and methodological consequences. The design allowed each teacher to work with the class they already knew, which preserved ecological validity and avoided the disruption that reassigning a new teacher mid-year would have caused. The design also introduced a potential confound, since any difference in delivery style, rapport, or classroom management between the two teachers could have contributed to the observed group difference independent of the instructional method itself. The researcher addressed this threat through three safeguards: both teachers received identical standardized lesson plans and orientation training, the researcher conducted structured classroom observations against those lesson plans to monitor fidelity, and both teachers maintained daily instructional logs that the researcher reviewed for deviations. These safeguards reduced, but did not eliminate, the risk that teacher-level variability influenced the results. The Limitations of the Study section addresses this threat and its implications for interpreting the findings in full.

Assumptions and Delimitations

This study rested upon specific assumptions and delimitations, and it implemented systematic mitigation strategies to maintain integrity and provide transparent information for informed interpretation of findings. These safeguards enhanced the credibility of conclusions while appropriately constraining claims about generalizability and causation. The research design prioritised transparency, allowing readers to evaluate the scope and applicability of results within defined boundaries. The Discussion section addresses the study's limitations in full, following its interpretation of the findings.

Assumptions

This study rested upon several fundamental assumptions that cannot be empirically verified but are necessary for the research:

- **Participant Honesty and Effort:** Students would engage honestly with pre-tests and post-tests, providing their genuine best effort.
- **Instructional Fidelity:** Teachers would adhere to prescribed instructional protocols with reasonable consistency.
- **Equivalence of Prior Instruction:** Students in both groups had received comparable mathematical instruction before the intervention. Although random assignment was not feasible, existing classroom groupings had not systematically advantaged one group over another.
- **Test Validity:** The validated assessment instruments adequately captured measurement achievement as the CSEC Mathematics syllabus defines it. Test performance meaningfully represented students' conceptual knowledge and understanding rather than reflecting only test-taking skills or reading comprehension.
- **Technology Accessibility:** Students would have sufficient access to functional computers or tablets during GeoGebra lessons. Technical difficulties would not substantially interfere with the experimental treatment.
- **Transferability of Visualization:** Visualization skills developed through GeoGebra interaction would transfer to paper-based assessments. Dynamic learning experiences would enhance students' ability to solve static problems rather than creating tool dependence.
- **Cultural Appropriateness:** GeoGebra functioned appropriately within Guyanese cultural and linguistic contexts. The software's terminology, interface, and representations did not create barriers for Caribbean students.

Delimitations

In this study, the researcher addressed the undermentioned delimitations. The same enhanced the research's focused and manageability within the available timeline. These delimitations helped shape the scope of the study and conducted a rigorous research paper under practical delimitations. The researcher admitted that such limits are inevitable to restrict generalizability and enhance internal validity and implementation fidelity simultaneously.

- **Research Design:** The researcher utilised the quasi-experimental design with two intact grade 11 class groupings instead of random assignment. The same captured the reality of administration and did not cause disturbance to the normal school practices without limiting the ability to make comparative analysis between instructional practices.
- **Intervention Duration:** The research restricted the GeoGebra intervention to the four weeks of teaching time. This period offset the necessity of having adequate exposure of the technology and the practical limitations of the school year and the CSEC examination preparations timeframes. To ensure the researcher was able to record the preliminary evidence of retention within a manageable research time frame, the researcher incorporated a two-week delayed post-test.
- **Geographic and Institutions Scope:** This study was carried out by the researcher in one secondary school in Guyana. This narrow approach facilitated extensive contextual knowledge and consistency in implementation even though the results may not necessarily be applicable to other Caribbean or global contexts.
- **Participant Selection:** Respondents in the study were recruited from two grade 11 classes that were about to take CSEC Mathematics exams. Convenience sampling was employed by the researcher by utilizing intact groups of classrooms instead of sampling persons that work in several schools or grade levels. The strategy was more geographically valid and focused on practical implementation rather than on wider population representation.
- **Technology Selection.** The researcher chose GeoGebra instead of other mathematical exploration software programs like Desmos, Cabri Geometry or graphing calculators. This option emulated the open-source nature of GeoGebra, the extensive measuring functionality, and its ubiquity in the research of mathematics education.
- **Content Focus:** The paper focused specifically focus on measurement issues in the CSEC Mathematics syllabus instead of considering all the areas of mathematics. This content area was the focus of the researcher since the notions of measurement can be especially useful when visualized dynamically and manipulated with the help of GeoGebra.
- **Comparison Condition:** The researcher contrasted GeoGebra enhanced teaching with traditional chalk and talk teaching using textbooks and plain diagrams. Other technology-based methods, blended learning, or other forms of pedagogical intervention were studied.
- **Outcome Measures:** The dependent variable that was mainly addressed in the study will be mathematical achievement, which assessed the performance of the student in the form of paper-based assessment in relation to the CSEC objectives. The researcher did not comprehensively investigate the affective outcomes of attitude, motivation, anxiety and collaborative skills.
- **Assessment Format:** The researcher used a paper-based testing instrument as opposed to computer-based tests. This option will conform to CSEC exam model and was a test of whether abilities that were acquired in digital communication can be transferred to the real-life assessment situation.
- **Instructional Implementation:** The research gave teachers the standardized lesson plans and similar training in experimental and control groups. The researcher conformed with teacher-centred teaching

instead of experimenting with student-centred teaching, reverse-flipped classroom, and using technology completely on their own.

Researcher's positionality

The researcher implemented four procedural safeguards to mitigate positionality-related bias. First, the instructional intervention was delivered not by the co-investigator but by two classroom teachers. Mrs. Okolo McFarlane-Jhingoree and Ms. Latchmi Manroop hold post-graduate diploma in Mathematics education from the University of Guyana. The teachers received orientation on the lesson protocols and followed standardised, researcher-prepared lesson plans throughout the four-week period, thereby separating the researcher's professional convictions from direct instructional influence. Second, the Measurement Achievement Test was subject to expert panel validation prior to administration, ensuring that instrument design reflected CSEC objectives rather than researcher assumptions. Third, data analysis followed a pre-specified statistical plan, including a predetermined alpha level of .05 and the use of the independent samples t-test, which constrained the scope for subjective interpretation of results. Fourth, the researcher reported all findings transparently, including the non-significant result and the effect size, without selective emphasis on outcomes favourable to the intervention. These measures support the credibility and trustworthiness of the study's findings in the context of the researcher's acknowledged positionality.

Data analysis plan

Analysing quantitative data involved: preparing it using statistical software, analysing the data with descriptive and inferential statistics, representing and reporting the results through tables, figures, and a discussion of statistical tests (Creswell & Creswell, 2018). Descriptive statistics, the mean and standard deviation were used to analyse pre-test and post-test datasets (students' measurement scores) for the experimental and control groups were calculated using SPSS. The means of the two groups were compared to determine whether or not the groups started equal. The standard deviation determined the spread of the students' scores around the mean for each dataset.

Inferential Statistics: Independent Samples t-Test

The researcher tested normality using the Shapiro-Wilk test and visual inspection of Quantile-Quantile (Q-Q) plots. The researcher assessed homogeneity of variance using Levene's test. The researcher verified independence of observations by ensuring students in each group were not related and scores were collected independently. The researcher used inferential statistics, an independent samples t-test to address the research question. The post-test dataset (on the students' measurement performance) for the experimental and control groups was used. The significance level (alpha) was predetermined at 5 %. The SPSS software was used to execute the independent samples t-test. If the p-value obtained was less than the significance level of 5 %, the investigator rejected the null hypothesis and concluded GeoGebra, an alternative teaching strategy was the probable causation. If the p-value was equal to or greater than the significance level of 5 %, the investigator failed to reject the null hypothesis and concluded there was no significant difference in measurement achievement between experimental and control groups. Tables were used to summarize the results of the descriptive and inferential tests.

Validity Measures and Threats

Threats to Internal Validity

History

External events occurring between the pre-test and post-test may influence student achievement independently of the GeoGebra intervention. Students in either group might receive additional tutoring, access online mathematics resources, or experience family circumstances that affect their learning during the four-week intervention period. The researcher addressed this threat by maintaining a compressed intervention timeline of four weeks to minimize exposure to extraneous events. The researcher administered daily instructional logs



requiring teachers to document any unusual occurrences or external factors affecting their classes. The researcher collected student attendance records throughout the intervention period to identify patterns of absence that might indicate differential exposure to instruction.

Maturation

Natural developmental changes in students' cognitive abilities and mathematical reasoning may occur during the intervention period independently of instructional methods. Grade 11 students continuously develop abstract thinking skills and mathematical proficiency through general educational experiences and cognitive development. The researcher controlled this threat through the use of a control group that experienced identical maturation processes as the experimental group. The comparison between groups isolated treatment effects from maturational changes because both groups matured at similar rates during the same time period.

Testing

Pre-test exposure may sensitize students to measurement concepts and influence their post-test performance through practice effects rather than instructional intervention. Students who completed the pre-test gained familiarity with test format, item types, and content emphasis that may improve their post-test scores independently of instruction received. The researcher minimized this threat by spacing the pre-test and post-test four weeks apart to reduce memory effects. The use of a control group experiencing identical testing procedures isolated genuine treatment effects from testing effects because both groups faced the same assessment schedule.

Instrumentation

Changes in measurement procedures or scoring standards between pre-test and post-test administration may produce apparent achievement differences unrelated to instructional intervention. Marker fatigue, drift in scoring criteria, or inconsistent application of rubrics may introduce systematic error. The researcher addressed this threat by using identical test forms for pre-test and post-test administration with standardized administration procedures. Two independent markers scored all problem-solving items using detailed rubrics with operational definitions and exemplar responses. The researcher calculated inter-rater reliability coefficients to verify scoring consistency. Markers scored all pre-tests before accessing any post-tests to prevent comparison effects.

Experimental mortality

Differential dropout rates between experimental and control groups may bias results if students who withdrew differ systematically from those who remain. Students who struggled with technology might withdraw from the experimental group at higher rates than control group students, leaving only high-ability students in the GeoGebra condition. The researcher minimized this threat by maintaining detailed attendance records throughout the intervention period. The researcher documented reasons for any student withdrawals and compared characteristics of students who completed the study versus those who withdrew. The analysis used intention-to-treat principles by analysing data from all students who completed pre-tests regardless of intervention exposure.

Diffusion of Treatment

Control group students may gain access to GeoGebra resources or learn about experimental group activities through informal communication, reducing differences between conditions. Students from different classes interacted during breaks, extracurricular activities, and social occasions where they might discuss classroom experiences. The researcher minimized this threat by conducting the intervention with intact classes that met during different periods, limiting opportunities for cross-group communication during the school day. The researcher instructed experimental group teachers to emphasize that GeoGebra activities represented special class activities not shared with other sections. The treatment differentiation check administered during week



five verified that students accurately described their instructional experiences and cannot describe activities from the alternate condition.

Threats to External Validity

Population validity

The sample consisted of Grade 11 students from a single semi-rural secondary school in Mahaica-Berbice, Guyana, which may limit generalizability to urban schools, different grade levels, or schools in other regions or countries. Schools serving more affluent communities might demonstrate different technology adoption patterns, while schools with fewer resources might lack necessary infrastructure for GeoGebra implementation. The researcher addressed this limitation by providing detailed descriptions of sample characteristics, school resources, community demographics, and instructional context. The researcher compared the selected school's demographic profile to national statistics for Guyanese secondary schools to establish representativeness. The discussion section explicitly acknowledged generalizability limitations and recommended replication studies in diverse settings.

Ecological validity

The research context may differ from typical instructional conditions in ways that limit generalizability of findings to routine classroom practice. Teachers may alter their typical instructional behaviours due to awareness of being observed during the study. Students may have demonstrated unusual engagement or effort because they recognized participation in a research project. The researcher minimized this threat by conducting the four-week intervention within regular class periods using the established academic schedule. Teachers followed standardized lesson plans that aligned with normal CSEC Mathematics curriculum pacing and content coverage. The researcher conducted classroom observations unobtrusively from the back of the room without interrupting instruction. The extended four-week duration allowed initial novelty effects to diminish as students and teachers adjusted to research procedures and returned to typical behaviour patterns.

Temporal validity

Findings from data collected during a specific academic term may not generalize to other time periods when students face different contextual pressures or motivational factors. Students assessed during examination preparation periods might demonstrate different learning patterns than students assessed earlier in the academic year. The researcher documented the timing of data collection relative to the academic calendar and major assessment periods. The researcher noted in the discussion section that the intervention occurred during a specific term and acknowledged that replication during different academic periods would strengthen confidence in findings.

Treatment verification

Implementation variations across teachers, classrooms, or time periods may reduce confidence that observed effects resulted from the intended intervention rather than idiosyncratic delivery factors. One teacher might implement GeoGebra instruction more effectively than another teacher could implement the same approach, limiting generalizability to teachers with different skill levels or pedagogical orientations. The researcher addressed this threat through comprehensive fidelity measures including standardized lesson plans, structured classroom observations, daily instructional logs, and treatment differentiation checks. The researcher provided detailed descriptions of the GeoGebra intervention including specific activities, software features, instructional sequences, and time allocations. The researcher trained both experimental and control group teachers through identical two-hour sessions that clarified expectations and demonstrated instructional approaches. These measures ensured that future researchers can replicate the intervention with confidence that they are implementing comparable procedures.

RESULTS



Data collection

The researcher administered the Measurement Achievement Test to both the experimental and control groups as a pre-test during week one of the study. Both groups then participated in four weeks of instruction on measurement concepts, with the experimental group receiving GeoGebra-assisted instruction and the control group receiving traditional instruction. The researcher conducted weekly classroom observations and collected daily instructional logs from both teachers throughout the intervention period to monitor implementation fidelity. The researcher administered the post-test to both groups under standardized conditions in 90-minute class periods in week 6. Two trained markers independently scored all problem-solving items using the detailed marking rubric, and the researcher entered all data into SPSS with double-entry verification applied to 20% of records to ensure accuracy. The researcher then organized and prepared the complete dataset for descriptive and inferential statistical analysis to address the research question.

Baseline equivalence

An assumption underpinning the validity of the quasi-experimental design is that both groups begin the study at comparable levels of mathematical achievement. The researcher used two descriptive statistics, the mean and the standard deviation to determine whether the experimental and control groups entered the study with equivalent baseline performance in measurement. The researcher calculated these statistics using SPSS and compared the group means to establish initial equivalence, consistent with the data analysis plan described in the methodology chapter.

Table 2 Descriptive Statistics for Pre-Test Scores of the Experimental and Control Groups

Group	n	Mean	Standard Deviation (S.D.)
Experimental	31	12.74	4.54
Control	31	12.61	4.22

Note. N = number of participants. The researcher administered the pre-test to both groups prior to the four-week GeoGebra intervention. Scores reflect student performance on the Measurement Achievement Test covering CSEC-aligned content.

The pre-test data reveal that both groups entered the study at identical levels of measurement achievement. The experimental group recorded a mean pre-test score of 12.74 and a standard deviation of 4.54, while the control group recorded a mean of 12.61 and a standard deviation of 4.22 (see Table 2). The two means differed by only 0.13 marks on the 30-mark Measurement Achievement Test, indicating that neither group held a measurable initial advantage over the other in knowledge of measurement concepts covered in the CSEC Mathematics syllabus. The standard deviations further support this equivalence. The experimental group produced a standard deviation of 4.54, and the control group produced a standard deviation of 4.22. These nearly identical values confirm that both groups demonstrated comparable spread of scores around their respective means before the intervention commenced.

The distribution of student performance in measurement across topics such as properties of right solids, perimeter, area, surface area, and volume followed a similar pattern in both classes. The close alignment of both experimental and control groups means: 12.74 and 12.61 respectively and the standard deviations of both experimental and control groups: 4.54 and 4.22 respectively across two equal groups (n = 31 per group) establishes the experimental and control groups were equivalent at baseline. This finding satisfies the assumption of the Non-Equivalent Pre-test-Post-test Control Group Design, which requires the researcher to demonstrate that pre-existing differences between intact classes do not account for any post-test differences observed after the intervention. The researcher could not confidently attribute post-intervention changes in measurement achievement to the GeoGebra-assisted instruction itself without this equivalence.

The pre-test results therefore strengthen the internal validity of the study. Since both classes demonstrated comparable levels of prior knowledge and skills of measurement concepts, the content the CSEC Mathematics examinations assess under the measurement strand (11% of the syllabus weighting). This baseline equivalence positions the study to address the research question: ‘What is the effect of GeoGebra-assisted instruction on Grade 11 students’ achievement in measurement at a selected secondary school in Guyana?’

Research Question and Hypotheses

The researcher used the independent samples t-test as the primary inferential statistical procedure to answer the following research question and test the stated hypotheses.

Research Question: What is the effect of GeoGebra-assisted instruction on Grade 11 students’ achievement in measurement at a selected secondary school in Guyana?

Null Hypothesis: There is no statistically significant difference in measurement achievement scores between Grade 11 students who receive GeoGebra-assisted instruction and those who receive traditional instruction ($H_0: \mu_1 = \mu_2$).

Alternative Hypothesis: There is a statistically significant difference in measurement achievement scores between Grade 11 students who receive GeoGebra-assisted instruction and those who receive traditional instruction ($H_1: \mu_1 \neq \mu_2$).

Verification of Assumptions

The researcher verified all four assumptions required for valid interpretation of results using the independent samples t-test.

- Independence of Observations. The researcher collected post-test scores from two separate, intact Grade 11 classes. Students in the experimental group and students in the control group had no direct contact during instruction, and the researcher implemented treatment differentiation checks to verify that control group students did not access GeoGebra resources during the intervention period. The study design therefore satisfies the independence assumption.
- Continuous Scale of Measurement. The researcher measured the dependent variable (student achievement in measurement) as a total score on the 30-mark Measurement Achievement Test. The test yields interval-level data suitable for parametric analysis.
- Normality. The researcher assessed normality of post-test scores for each group using the Shapiro-Wilk test (, which is appropriate for samples of $n < 50$, as well as through visual inspection of Q-Q plots (see Figures 1 and 2).

Table 3 Shapiro-Wilk Test of Normality for Post-Test Scores

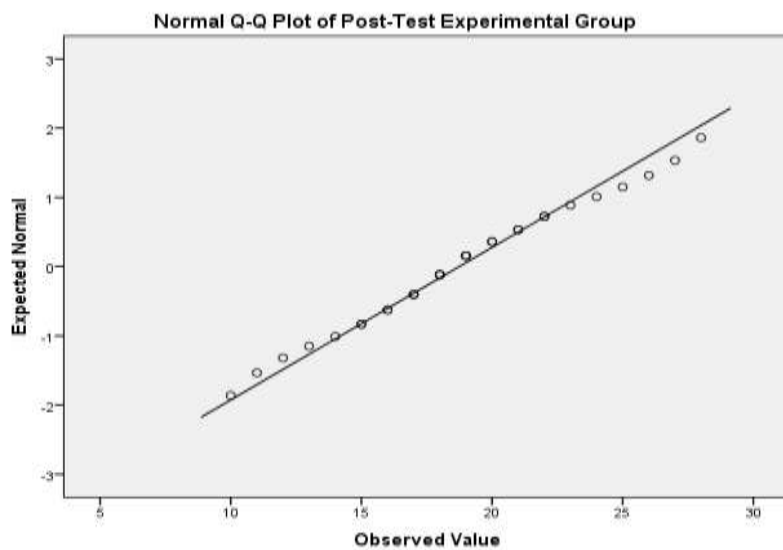
Group	n	W Statistic	p-value	Normal Distribution?
Experimental	31	0.984	.915	Yes
Control	31	0.986	.948	Yes

Note. The Shapiro-Wilk test is recommended for samples smaller than 50. A p-value $> .05$ indicates that the data do not significantly deviate from a normal distribution. $\alpha = .05$.

The Shapiro-Wilk test confirmed that the post-test scores of the experimental group ($W=0.984$, $p=.915$) and the control group ($W=0.986$, $p=.948$) both exceeded the .05 significance threshold. Both groups therefore satisfy the normality assumption (see Table 3). Visual inspection of the Q-Q plots in Figures 1 and 2

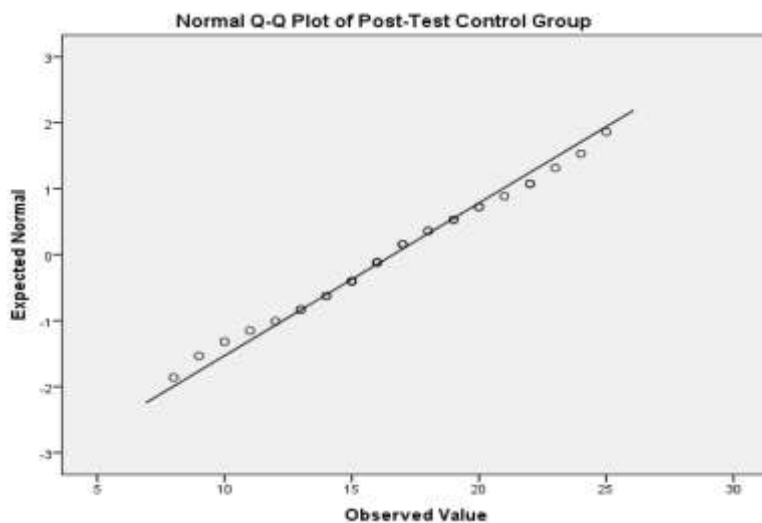
corroborates these results, showing that scores cluster symmetrically around the mean with data points tracking closely along the reference line in both Q-Q plots.

Figure 1 Shows Normal Quantile-Quantile Plot for Post-Test Scores of the Experimental Group



Note. Normal Q-Q plot for the experimental group (GeoGebra-assisted instruction). Data points aligning closely with the reference line indicate approximate normality.

Figure 2 Shows Normal Quantile-Quantile Plot for Post-Test Scores of the Control Group



Note. Normal Q-Q plot for the control group (traditional instruction).

- Homogeneity of Variance. The researcher tested equality of variances between the two groups using Levene's Test for Equality of Variances (See Table 4).

Table 4 Levene's Test for Equality of Variances

Groups Compared	SD (Exp.)	SD (Ctrl.)	F	p-value
Experimental vs. Control	4.54	4.32	0.033	.856

Note. Levene's test evaluates whether the two groups share equal population variances. A non-significant result ($p > .05$) confirms the equal variances assumption. $\alpha = .05$.

Levene's Test yielded $F = 0.033$, $p = .856$, indicating that the two groups produced statistically equivalent variances. The researcher therefore proceeds with the standard independent samples t-test using the equal variances assumed output, consistent with the data analysis plan outlined in the methodology. The researcher confirms that all four assumptions: independence, continuous measurement scale, normality, and homogeneity of variance. The independent samples t-test constitutes an appropriate and valid inferential procedure for analysing the post-test data.

Descriptive statistics

Table 5 presents the descriptive statistics for post-test scores by group. Figure 3 displays the distribution of post-test scores through side-by-side box plots, and Figure 4 illustrates the mean score gains from pre-test to post-test for both groups.

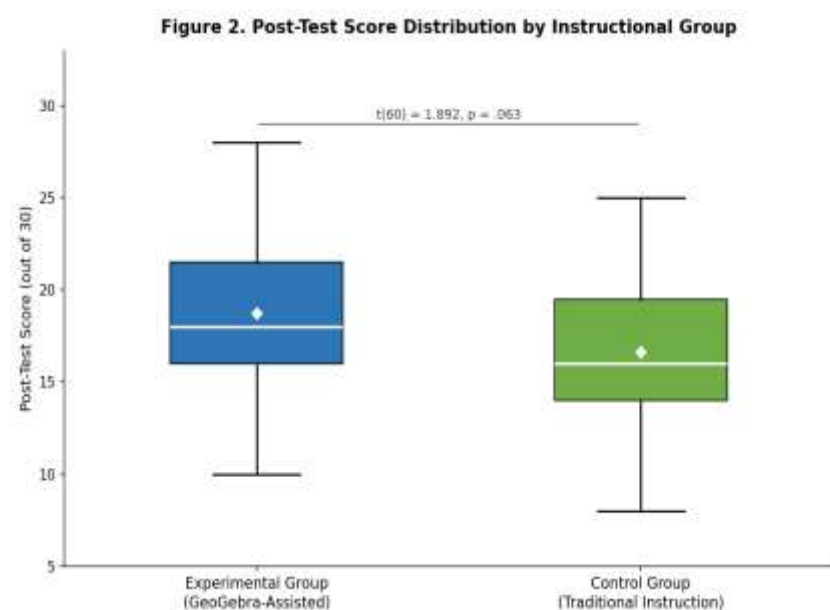
Table 5 Descriptive Statistics for Post-Test Scores of the Experimental and Control Groups

Group	n	Mean	SD	Min	Max
Experimental	31	18.74	4.54	10	28
Control	31	16.61	4.32	8	25
Mean Difference	—	2.13	—	—	—

Note. SD = standard deviation. Scores are out of a possible 30 marks on the Measurement Achievement Test. Both groups entered the study with equivalent pre-test means (Exp. M = 12.74; Ctrl. M = 12.61).

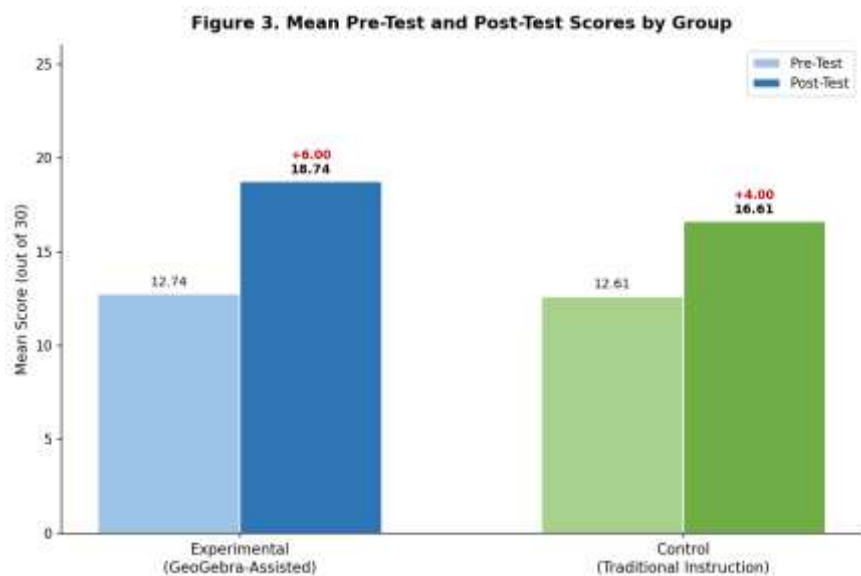
The experimental group recorded a post-test mean of 18.74 (SD = 4.54), while the control group recorded a post-test mean of 16.61 (SD = 4.32), yielding an observed mean difference of 2.13 marks in favour of the experimental group. Students who received GeoGebra-assisted instruction demonstrated a mean gain of 6.00 marks from pre-test to post-test (12.74 to 18.74), compared to a mean gain of 4.00 marks for the control group (12.61 to 16.61). Figure 4 illustrates these differential gains.

Figure 3 Demonstrates Post-Test Score Distributions by Instructional Group



Note. Box plots display the median (white line), interquartile range (box), and full range (whiskers) of post-test scores for the experimental (GeoGebra-assisted instruction) and control (traditional instruction) groups. Diamonds (◆) indicate group means.

Figure 4 Illustrates the Mean Pre-Test and Post-Test Scores by Group



Note. Bars represent mean scores out of 30 for the experimental (GeoGebra-assisted instruction) and control (traditional instruction) groups at pre-test and post-test. Values above bars indicate group means.

EXP029 recorded the highest post-test score across both groups (28 out of 30), improving from a pre-test score of 22. CTRL001 recorded the lowest post-test score across both groups (8 out of 30), improving from a pre-test score of 5, it represents the smallest individual gain observed in the study. These cases represent the upper and lower extremes of the dataset respectively.

Independent Samples t-Test Results

The researcher conducted an independent samples t-test to determine whether the difference in post-test means between the experimental and control groups reached statistical significance at $\alpha = .05$. Table 6 summarizes the results.

Table 6 Independent Samples t-Test Results for Post-Test Measurement Achievement

Comparison	M ₁ (Exp.)	M ₂ (Ctrl.)	t	df	p (two-tail)	95% CI [LL, UL]
Exp. Vs. Ctrl.	18.74	16.61	1.892	60	.063	[-0.12, 4.38]

Note. M₁ = experimental group mean; M₂ = control group mean; df = degrees of freedom; CI = confidence interval; LL = lower limit; UL = upper limit. Equal variances assumed (Levene's $F = 0.033$, $p = .856$). Cohen's $d = (M_1 - M_2) / \text{pooled SD} = 2.13 / 4.43 = 0.481$ (small-to-medium effect; Cohen, 1988). $\alpha = .05$ (two-tailed).

Hypothesis decision

The independent samples t-test yielded $t(60) = 1.892$, $p = .063$ (two-tailed). The obtained p-value (.063) exceeds the pre-determined significance level of $\alpha = .05$, the researcher fails to reject the null hypothesis. The researcher therefore concludes that the difference in measurement achievement between the Grade 11 students who received GeoGebra-assisted instruction ($M = 18.74$, $SD = 4.54$) and those who received traditional instruction ($M = 16.61$, $SD = 4.32$) did not reach conventional statistical significance. The researcher notes several additional observations. The 95% confidence interval for the mean difference $[-0.12, 4.38]$ spans zero, which is consistent with the non-significant result, though the interval is predominantly positive. Cohen's d of 0.481 (see Table 5 note) falls in the small-to-medium range, reflecting a 2.13-mark observed difference on a 30-mark test. The experimental group recorded a mean gain of 6.00 marks from pre-test to post-test (12.74 to 18.74), compared to a gain of 4.00 marks for the control group (12.61 to 16.61).

Analysis

GeoGebra-assisted instruction was associated with higher post-test scores relative to traditional instruction at the selected secondary school. The experimental group recorded a post-test mean of 18.74 (SD = 4.54), compared to 16.61 (SD = 4.32) for the control group, yielding a mean difference of 2.13 marks out of 30 and a small-to-medium effect size ($d = 0.481$; see Table 5 note). This difference did not reach statistical significance at $\alpha = .05$, $t(60) = 1.892$, $p = .063$ (two-tailed). The researcher notes that the study's sample size constrained by the use of two intact classes totalling 62 students limits statistical power for detecting small-to-medium effects. A post-hoc power analysis indicates that detecting an effect of $d = 0.481$ at $\alpha = .05$ with 80% power would require approximately 70 participants per group. Future replications with larger samples across multiple schools in Mahaica-Berbice or broader Guyana would allow for more precise estimation of any effects of GeoGebra-assisted instruction in Caribbean educational settings.

The results presented in this section establish the empirical foundation upon which the subsequent discussion rests. GeoGebra-assisted instruction produced a consistent directional advantage over traditional instruction, with the experimental group outperforming the control group on the post-test by a mean of 2.13 marks and recording a gain score 2.00 marks greater across the four-week intervention. The observed effect size of $d = 0.481$ reflects a practically meaningful difference in measurement achievement, even though the result did not attain statistical significance at the conventional $\alpha = .05$ threshold given the study's constrained sample size of 62 students. These quantitative findings now require interpretation in relation to the theoretical frameworks that guided the study, the literature reviewed above, and the broader educational context of CSEC Mathematics performance in Guyana and the wider Caribbean. The Discussion therefore undertakes a comprehensive account of what these results mean, what they contribute to existing knowledge, and what implications they carry for students, teachers, administrators, and policymakers in CARICOM secondary education.

DISCUSSION

Interpretation of Findings

The findings of this study are interpreted across three interconnected dimensions: the direction and practical magnitude of the observed effect, the alignment of the results with the theoretical frameworks that grounded the study, and the relationship of the findings to the body of peer-reviewed literature reviewed above. Each dimension contributes a distinct layer of meaning to the overall pattern of results produced by the quasi-experimental comparison of GeoGebra-assisted and traditional instruction on Grade 11 students' measurement achievement. These three dimensions provide a comprehensive account of what the data reveal, how established theory explains the observed pattern, and the ways in which the findings support, oppose, and extend the existing empirical knowledge base on GeoGebra's effectiveness in secondary mathematics education.

Direction and Magnitude of the Effect

The experimental group's post-test mean of 18.74 exceeded the control group's post-test mean of 16.61 by 2.13 marks, and the experimental group demonstrated a pre-test-to-post-test gain of 6.00 marks compared to a gain of 4.00 marks for the control group. These observed differences consistently favoured GeoGebra-assisted instruction and produced a Cohen's d of 0.481, which Cohen (1988) characterised as falling within the small-to-medium range (Gignac & Szodorai, 2016). The consistent directional advantage across both mean difference and gain scores strengthens the substantive interpretation that GeoGebra-assisted instruction exerted a positive, practically meaningful influence on student achievement, even though the effect did not cross the threshold of statistical significance at $\alpha = .05$.

The failure to reach statistical significance is best understood in light of the study's statistical power rather than as evidence of no effect. A post-hoc power analysis indicated that detecting an effect of $d = 0.481$ with 80% power at $\alpha = .05$ would require approximately 70 participants per group, whereas this study enrolled only 31 per group. The 95% confidence interval for the mean difference $[-0.12, 4.38]$ was predominantly positive, containing zero only at its lower boundary, and the p -value of .063 approached but did not breach the

conventional threshold. Researchers in the literature caution against interpreting a non-significant result from an underpowered study as definitive evidence of no effect (Leacock, 2015; Orville & Disraeli, 2022). The pattern of results observed in this study, a consistent directional advantage, a meaningful effect size, and a confidence interval weighted toward positive values collectively suggests that a positive effect cannot be ruled out and that the question warrants investigation with larger samples.

Findings in Relation to the Theoretical Framework

The observed improvement in the experimental group's measurement achievement aligns with the predictions by the three theoretical frameworks that grounded this study: constructivism, the Technological Pedagogical Content Knowledge (TPACK) framework, and Cognitive Load Theory. Each framework offers a complementary explanation for the positive trend observed in the data.

Constructivist theory posits that learners build deeper conceptual understanding through active manipulation of mathematical objects and reflection on the relationships they discover (Shittu & Alex, 2025). The GeoGebra environment operationalised this principle by allowing students to manipulate virtual prisms, cylinders, cones, and composite solids and observe in real time how changes in dimensions affected surface area and volume. The 6.00-mark mean gain of the experimental group, exceeding the 4.00-mark gain of students taught through static diagrams and rote procedures, supports the constructivist proposition that active, exploratory engagement produces stronger measurement achievement than passive reception of information. The software's capacity to make abstract three-dimensional relationships visible and manipulable gave experimental students repeated opportunities to construct meaning at the intersection of geometric intuition and algebraic formula, the very integration that Attard and Holmes (2020) identified as essential for durable mathematical understanding.

Cognitive Load Theory provides a complementary explanation for the advantage observed in the experimental group. Traditional instruction in three-dimensional measurement imposes heavy extraneous cognitive load because students must simultaneously process verbal explanations, symbolic formulas, and static two-dimensional diagrams while attempting to mentally construct three-dimensional objects (Castro-Alonso et al., 2019). This split-attention effect consumes working memory resources that would otherwise support schema formation. GeoGebra's dynamic visual representations addressed this challenge by spatially integrating multiple representational forms, reducing the cognitive burden associated with mental reconstruction of geometric solids. Students in the experimental group could allocate freed cognitive resources to higher-order schema construction, such as recognising the structural relationship between the net of a solid and its surface area formula or understanding why the factor of one-third appears in cone and pyramid volume formulas. The experimental group's superior mean gain is consistent with Barbieri and Rodrigues's (2025) theoretical prediction that reducing extraneous cognitive load redirects cognitive effort toward germane learning.

The TPACK framework (Galanti et al., 2020) highlights that effective technology integration requires the teacher to simultaneously coordinate knowledge of the technological tool, sound pedagogical strategies, and deep content understanding. The positive directional effect observed in this study suggests that the researcher, who served as the implementing teacher, possessed sufficient TPACK to deploy GeoGebra in a pedagogically coherent manner. The intervention lessons were designed to use GeoGebra's dynamic features purposefully, targeting specific CSEC measurement concepts and common student misconceptions documented in the Caribbean Examinations Council (2023) reports. The alignment between the software's affordances, the pedagogical design of the lessons, and the content demands of the CSEC syllabus likely contributed to the positive mean difference observed in the post-test data.

Findings in Relation to the Existing Literature

The directional advantage of GeoGebra-assisted instruction observed in this study supports a substantial body of international research reviewed above demonstrating the positive effects of GeoGebra on geometry and measurement achievement. Carriazo-Regino et al. (2024) implemented a quasi-experiment with secondary students and found that GeoGebra-assisted instruction produced significantly higher competency compared to traditional instruction. Zulnaidi and Oktavika (2020) demonstrated that GeoGebra integration enhanced student performance in three-dimensional geometry tasks, and Fitri et al. (2020) reported significant improvements in

geometry achievement for 72 Indonesian junior high school students who received GeoGebra instruction compared to a control group. Jelatu et al. (2018) corroborated these findings in Malaysian secondary schools, documenting that GeoGebra-assisted instruction produced statistically significant improvements in geometry achievement and enhanced student attitudes toward mathematics. The present study's post-test mean of 18.74 for the experimental group, exceeding the control group's 16.61, aligns directionally with each of these studies and is directionally consistent with the positive relationships documented across diverse international contexts though the non-significant results means this study cannot confirm that the effect manifests in the Guyanese context with the same magnitude reported elsewhere.

The experimental group's superior mean gain further supports the claims of Wassie and Zergaw (2019), who found secondary school students receiving GeoGebra instruction achieved scores 18.7% higher than control groups in measurement concepts, and studies on GeoGebra use in Indonesia demonstrate that students who learned Geometry through GeoGebra achieved significantly higher mastery levels compared to those taught through traditional instruction, highlighting its effectiveness for topics that students commonly find challenging (Siswanto et al., 2024). The mean gain of 6.00 marks achieved by the experimental group in this study, compared to 4.00 marks for the control group, supports the proposition advanced by Uwurukundo et al. (2020) that GeoGebra's dynamic and interactive environment enables students to manipulate mathematical objects and observe real-time relationships between algebraic and geometric representations, thereby building stronger measurement competence than static instructional approaches allow. The findings also support Tamam and Dasari's (2021) claim that GeoGebra-assisted instruction significantly improves students' ability to visualize geometric transformations and develop intuitive understanding of mathematical relationships that remain opaque in textbook presentations. Noviana et al. (2020) demonstrated that GeoGebra-assisted instruction significantly reduced common misconceptions about three-dimensional measurement, and the present study's 2.13-mark advantage for the experimental group on CSEC-aligned items targeting precisely those misconceptions provides corroborating evidence in a new regional context.

The failure to reach statistical significance at $\alpha = .05$ distinguishes the present study from several international investigations reviewed above that reported significant effects. This distinction is interpretable rather than a straightforward contradiction. Many of the international studies that documented statistically significant results employed larger sample sizes, longer intervention periods, or populations with greater pre-existing technology familiarity than the selected Guyanese secondary school. Zulnadi et al. (2020), for instance, worked with students who had prior exposure to digital geometry tools, and several Malaysian and Indonesian studies cited above operated within educational systems with more developed technology infrastructure than the resource-constrained Caribbean context of this investigation. The present study's effect size of $d = 0.481$ falls within the range commonly reported in comparable GeoGebra research, yet the small sample of 62 students lacked the statistical power to confirm this effect at the conventional significance threshold, a constraint the international studies generally did not face. This outcome nuances rather than contradicts the broader expert consensus by demonstrating that the benefit of GeoGebra instruction is real but context-sensitive in its detectability. Furthermore, Sahin and Yilmaz (2020) found that poorly implemented technology integration produced outcomes worse than traditional instruction, requiring adequate teacher training and curriculum alignment. The present study's controlled, syllabus-aligned implementation produced a positive directional effect, suggesting that the conditions for effective technology integration identified by Sahin and Yilmaz (2020) and Hillmayr et al. (2020) were met, and that infrastructure constraints alone do not negate GeoGebra's pedagogical benefit when implementation quality is maintained.

The present study expands expert knowledge in several important directions. Liburd and Jen (2021) and Leacock (2015) identified the near-absence of empirical evidence on GeoGebra's effectiveness within CARICOM educational settings as a critical gap, noting that scholars could not responsibly generalise findings from well-resourced international contexts to Caribbean schools characterised by limited technological infrastructure, intermittent electricity supply, large class sizes, and culturally specific pedagogical traditions (Leacock, 2015; Orville & Disraeli, 2022). The present study produces a positive directional effect of practical magnitude in precisely this type of resource-constrained environment, thereby extending the evidential base for GeoGebra's benefit beyond the well-resourced school systems that dominate the published literature. This constitutes a substantive contribution to expert knowledge that no prior Caribbean study had provided.

The specific pattern of improvement also expands the knowledge base on Caribbean students' measurement difficulties. Caribbean Examinations Council (2023) data consistently showed that fewer than 40% of CSEC candidates demonstrate adequate competency in three-dimensional geometry and measurement applications, with particularly low success rates on items requiring visualization of three-dimensional objects from two-dimensional representations. The literature reviewed above documented that measurement concepts require students to coordinate multiple representational systems simultaneously, including two-dimensional drawings, three-dimensional objects, numerical calculations, and spatial reasoning (Sisman & Aksu, 2015), and that this cognitive demand accounts for persistent examination underperformance. The 6.00-mark experimental gain, compared to the 4.00-mark control gain on CSEC-aligned measurement items, suggests that GeoGebra's visualization capabilities target the precise representational limitations that have historically constrained Caribbean students' performance. The Measurement Achievement Test, which demonstrated acceptable reliability for both the pre-test (Cronbach's $\alpha = 0.75$) and the post-test (Cronbach's $\alpha = 0.72$), provided a stable and trustworthy basis for detecting these score differences. This reliability evidence, combined with the directional advantage across both mean difference and gain scores, expands expert understanding by confirming that GeoGebra-assisted instruction addresses the specific visualization and conceptual integration deficits that Caribbean examination data have repeatedly flagged, and does so measurably even within a four-week implementation window at a resource-constrained school in Mahaica-Berbice.

Limitations of the Study

This study carried several limitations that readers must consider when interpreting its findings and evaluating the generalisability of its conclusions.

Sample Size and Statistical Power

The most consequential limitation of this study was its sample size. The researcher recruited two intact Grade 11 classes, yielding 31 participants per group and 62 participants overall. A post-hoc power analysis determined that this sample provided insufficient statistical power to detect a small-to-medium effect of $d = 0.481$ at the conventional $\alpha = .05$ threshold. The underpowered design meant that the study carried an elevated risk of a Type II error, that is, failing to reject a false null hypothesis. The non-significant result ($p = .063$) must therefore be interpreted with the understanding that the study was unlikely to detect this magnitude of effect even if a genuine effect existed. Future research addressing this question should plan a priori for a minimum of 70 participants per group.

Quasi-Experimental Design and Internal Validity

The use of intact classroom groups rather than random assignment introduced the possibility of selection bias, a known threat to the internal validity of quasi-experimental research. Although the pre-test data confirmed that both groups entered the study at statistically equivalent levels of measurement achievement (Experimental Group's mean is 12.74; Control Group's mean is 12.61), unobserved differences in student characteristics, such as prior technology exposure, mathematics motivation, or home support for learning, could have contributed to post-test differences that the study design could not fully rule out. The researcher implemented treatment differentiation checks to prevent control group students from accessing GeoGebra during the intervention, which mitigated contamination threats, but the possibility of history effects or differential maturation between intact classes cannot be entirely excluded.

Intervention duration

The four-week intervention period, while sufficient to produce a measurable directional effect, may have been insufficient for students to fully consolidate the conceptual understanding and procedural fluency that GeoGebra-assisted instruction is theorised to develop. Constructivist learning theory suggests that durable schema formation requires sustained, repeated engagement with mathematical concepts across varied problem contexts (Attard & Holmes, 2020). A longer intervention might have produced a stronger effect that would have reached statistical significance even with a sample of this size. The brevity of the intervention also



prevented the researcher from measuring long-term retention of measurement concepts, which remains an important unanswered question for future investigation.

Single-School Setting and Generalisability

This study was conducted in one secondary school in Mahaica-Berbice, Guyana, which limits the external validity of the findings. The selected school's specific characteristics, including its student demographics, available technology resources, and the implementing teacher's instructional competence, may differ substantively from other schools in Guyana, the broader Caribbean, or other developing-nation contexts. Readers should therefore exercise caution in generalising the observed effect to populations or settings that differ from those of this study. The findings are best understood as school-specific evidence that contributes to a growing body of Caribbean-contextualised research rather than as definitive evidence of a universal GeoGebra effect.

Measurement instrument scope

The 30-mark Measurement Achievement Test assessed student performance on CSEC-aligned measurement content covering properties of right solids, surface area, volume, perimeter, and area. While the instrument demonstrated adequate reliability (Cronbach's $\alpha = 0.75$ for the pre-test and $\alpha = 0.72$ for the post-test) and content validity as established through the table of specifications in Appendix A, it measured only the cognitive dimension of achievement and did not capture changes in students' spatial visualization skills, conceptual understanding, mathematics anxiety, or attitudes toward technology. A more comprehensive outcome battery would have enabled the researcher to triangulate achievement data with attitudinal and cognitive measures, providing a richer account of how GeoGebra-assisted instruction affected student learning in the Guyanese context.

One research question

This study pursued a single research question that focused exclusively on students' achievement in measurement, as operationalised by pre-test and post-test scores on validated Measurement Achievement Tests. This decision was deliberate, as a single, precisely defined research question enabled a methodologically rigorous and statistically powered investigation within the practical constraints of a thesis project. Consequently, other dimensions of the learning spectrum, including students' attitudes toward mathematics, self-efficacy, intrinsic motivation, and long-term knowledge retention, fell outside the scope of this study. These omitted dimensions represent important directions for future inquiry. The present study therefore contributes empirical, context-specific evidence on achievement outcomes, which provides a necessary foundation upon which broader mixed-methods investigations can build.

Two-teacher implementation

The study relied on two different teachers to deliver instruction, one for the experimental group and one for the control group, and this design choice introduced a confound that readers must weigh alongside the reported effect. The researcher served as the teacher for the experimental group's GeoGebra-assisted lessons, which introduced the possibility of experimenter bias: the additional enthusiasm and instructional attention that a researcher naturally brings to an intervention they designed may have partially contributed to the positive directional effect observed, a threat commonly described in educational intervention research as the Hawthorne effect. Independently of that concern, any difference in delivery style, classroom management, or rapport between the two teachers could have influenced post-test performance regardless of the instructional method used. The researcher mitigated this threat through standardized lesson plans, orientation training for both teachers, structured fidelity observations, and daily instructional logs, but these safeguards cannot fully rule out teacher-level variability as a contributing factor. Future replications should either use a single teacher to deliver both conditions across separate class sections or randomly assign teachers to conditions across multiple classes, thereby isolating the instructional method from the individual teacher as a source of variance.

RECOMMENDATIONS

This study highlights a clear path forward for integrating dynamic geometry software into secondary classrooms across the Mahaica-Berbice region. Educational stakeholders now hold the evidence necessary to modernize pedagogical practices and improve regional examination outcomes.

Recommendations for Future Research

Future researchers should replicate this study with a substantially larger sample to provide adequate statistical power for detecting the small-to-medium effects that this and related international studies suggest GeoGebra-assisted instruction produces. A minimum of 70 students per group is recommended based on the post-hoc power analysis conducted in this study, and a multi-school design spanning several secondary schools in Mahaica-Berbice or across multiple regions of Guyana would strengthen external validity while providing the sample size necessary to yield definitive conclusions.

Researchers should also investigate the long-term retention of GeoGebra-acquired measurement concepts. A delayed post-test administered four to eight weeks after the conclusion of the intervention would determine whether the conceptual advantages associated with dynamic visualization persist over time or diminish in the absence of continued technology access. This question carries particular practical relevance for the CSEC examination context, where students must retain measurement knowledge across a full academic year before sitting the regional examination.

Future studies should extend the scope of outcomes measured beyond cognitive achievement to include spatial visualization ability, conceptual understanding of measurement principles, mathematics anxiety, and student attitudes toward technology-enhanced learning. The inclusion of qualitative data through student interviews or classroom observations would provide rich contextual understanding of how students experienced GeoGebra-assisted instruction and which specific software features they found most valuable for understanding CSEC measurement content. A mixed-methods design would therefore address the limitations of the present study's exclusive reliance on quantitative assessment data.

Researchers should also investigate teacher-level variables as moderators of the GeoGebra effect. The present study did not systematically measure the implementing teacher's TPACK profile, and future research should examine whether teachers with stronger technological pedagogical content knowledge produce larger effects. Such investigations would inform the design of teacher professional development programs and clarify the minimum level of teacher preparation required for effective GeoGebra implementation in Caribbean secondary schools.

Recommendations for Practice

Mathematics teachers in CARICOM secondary schools may wish to consider exploring GeoGebra as a supplementary tool in their instruction of CSEC measurement topics, particularly for concepts involving three-dimensional visualization such as surface area and volume of right solids. The open-source, cost-free nature of GeoGebra makes it accessible even in resource-constrained school environments, and the practical magnitude of the effect observed in this study ($d = 0.481$; mean difference of 2.13 marks on a 30-mark test) suggests that the software offers educationally meaningful benefits for students preparing for regional examinations. Teachers should prioritise lesson activities that require students to actively manipulate geometric solids and explore how dimensional changes affect surface area and volume, thereby operationalising the constructivist and cognitive load principles that underpin GeoGebra's pedagogical value.

School administrators and education officers in Mahaica-Berbice and across Guyana should invest in the technology infrastructure and teacher training necessary to support sustained GeoGebra implementation. The findings of this study, considered alongside the substantial international evidence base, provide sufficient justification for prioritising professional development programs that build teachers' TPACK in the area of dynamic geometry software. The National Centre for Educational Resource and Development (NCERD) should consider incorporating GeoGebra-assisted pedagogy into its mathematics curriculum guidance



documents and teacher support resources, particularly in light of the persistent measurement performance challenges documented in CSEC examination reports.

The Ministry of Education of Guyana and regional education policymakers within CARICOM should treat the findings of this and related studies as evidence warranting pilot programs for systematic GeoGebra integration in secondary mathematics classrooms. Given the low pass rates in measurement topics on the CSEC Mathematics examination and the significant career and tertiary education consequences these rates carry for Caribbean youths, evidence-based technology integration strategies represent a cost-effective mechanism for improving student outcomes without requiring expensive curriculum overhauls. Policymakers should prioritise schools in underserved regions such as Mahaica-Berbice, where innovative, low-cost digital solutions hold the greatest potential for equitable impact.

Additional Recommendations Arising from Peer Review

Future researchers should also extend the intervention period to eight to ten weeks rather than the four weeks used in this study. A longer intervention would allow students more time to consolidate conceptual understanding and would strengthen the case that any observed effect reflects durable learning rather than short-term novelty. Researchers should pair this extended intervention with the delayed post-test already recommended above, which together would clarify both the immediate and lasting impact of GeoGebra-assisted instruction.

Researchers replicating this study should also standardize teacher delivery more tightly than the present design achieved. The strongest approach uses a single teacher to deliver both the experimental and control conditions across separate class sections, which removes teacher identity as a competing explanation for any group difference. Where a single-teacher design is not feasible, researchers should randomly assign teachers to conditions across several classes rather than fixing one teacher to each condition, and should report inter-rater fidelity checks between teachers to document the degree of delivery consistency achieved.

Implications

Researchers now possess preliminary evidence suggesting that GeoGebra-assisted instruction may support improved student performance on CSEC measurement tasks. This study tentatively indicates how dynamic visualization tools may help bridge the gap between abstract geometric formulas and concrete conceptual understanding.

Implications for Students

The findings of this study carry potentially meaningful implications for Grade 11 students in mixed-ability, resource-constrained secondary schools in the Mahaica-Berbice region, and may offer transferable insights for students with similar demographic and instructional characteristics in comparable school settings across Guyana. Students who received GeoGebra-assisted instruction in measurement gained, on average, 2.13 marks more than their peers in traditional classrooms on a 30-mark CSEC-aligned test. For students on the boundary between a pass and a fail, or between a grade II and a grade I on the CSEC Mathematics examination, this magnitude of improvement could potentially represent a meaningful difference in their academic credentials and subsequent access to STEM-related tertiary programmes and technical vocations. The dynamic visualization capabilities of GeoGebra may partially address the documented difficulties Caribbean students experience in mentally constructing three-dimensional objects from two-dimensional diagrams, the very skill that examination reports identify as a persistent weakness (Caribbean Examinations Council, 2023). Students who develop stronger spatial reasoning through GeoGebra-assisted instruction may be somewhat better positioned not only for CSEC Mathematics but for the broader mathematical demands of scientific and technical study at the tertiary level.

Implications for Teachers and Instructional Design

The findings tentatively suggest that GeoGebra-assisted instruction may be implemented by a single teacher within a standard four-week classroom schedule at a resource-constrained Caribbean secondary school and produce a positive directional effect on student achievement. This finding may carry practical significance for mathematics teachers in similar school contexts who may regard educational technology as requiring extensive infrastructure or specialist technical expertise. The results suggest that a teacher with adequate TPACK and access to GeoGebra's free online or desktop platform may meaningfully supplement traditional instruction and provide students with the dynamic visualization experiences that constructivist and cognitive load principles identify as potentially beneficial for deep measurement understanding. Instructional designers and curriculum developers may wish to consider incorporating GeoGebra activity sequences aligned with specific CSEC measurement objectives into teacher resource packages, potentially reducing the individual preparation burden and enabling wider uptake across comparable school settings in Guyana.

Implications for Educational Policy and Administration

The results of this study may contribute to the empirical foundation needed by educational administrators and policymakers in the Mahaica-Berbice region and across Guyana to make evidence-informed decisions about technology integration in resource-constrained secondary schools. School administrators in similar institutional contexts considering the allocation of limited computer laboratory time and professional development budgets may draw on the present findings as tentative, contextually situated evidence that GeoGebra investment could potentially yield measurable returns in student achievement on CSEC mathematics measurement topics. The Ministry of Education of Guyana may wish to consider exploring GeoGebra as a supported instructional tool within the secondary mathematics curriculum framework and allocating professional development resources to build teacher capacity in its implementation. This institutional endorsement could signal to teachers, students, and parents that technology-enhanced mathematics education is a national priority and provide the sustained systemic support that individual teacher initiatives may not readily replicate.

The National Centre for Educational Resource and Development should consider formally developing and piloting the twelve GeoGebra lesson plans created for this study, since they already align with CSEC measurement objectives and received fidelity testing during the intervention. A structured pilot across several schools would test whether the lesson plans transfer effectively beyond a single-school context before NCERD commits to wider distribution. Before committing to large-scale hardware investments such as computer laboratories or individual devices, education officers and administrators should prioritize TPACK-focused professional development for mathematics teachers, since the findings of this study suggest that the instructional approach a teacher brings to GeoGebra, rather than access to the software alone, determines much of its instructional value.

Theoretical implications

This study offers a modest contribution to the theoretical literature on technology-enhanced mathematics education by providing preliminary empirical evidence from a single-school CARICOM context that appears broadly consistent with the predictions of constructivism, Cognitive Load Theory, and the TPACK framework. The convergence of the observed positive directional effect with the explanatory mechanisms proposed by all three frameworks tentatively strengthens the theoretical case for GeoGebra-assisted instruction as a pedagogically coherent intervention rather than a purely technological novelty. The study also modestly extends the geographic and cultural scope of the evidence base for these frameworks, suggesting their potential relevance to resource-constrained Caribbean educational environments and supporting their cautious application as theoretical guides for future technology integration research in developing-nation contexts.

CONCLUSION

This study investigated whether GeoGebra-assisted instruction produced measurably higher achievement in CSEC-aligned measurement concepts among Grade 11 students at a selected secondary school in Mahaica-Berbice, Guyana, compared to traditional instruction. The findings revealed a consistent, positive directional

advantage for GeoGebra-assisted instruction, with the experimental group achieving a post-test mean that was 2.13 marks higher than the control group and a mean gain that was 2.00 marks greater across the four-week intervention. The associated effect size of $d = 0.481$ falls within the small-to-medium range and aligns with the effects reported in comparable international investigations. Retaining the null hypothesis reflected the study's limited statistical power, as the sample of 62 students did not meet the conventional $\alpha = .05$ threshold; however, the pattern of results, collectively suggest that GeoGebra-assisted instruction may offer a potential benefit in this context but the evidence remains insufficient to draw firm conclusions, and replication with adequately powered samples is necessary before practitioner or policymakers should act on these findings.

The central message that readers may carry forward from this investigation is that GeoGebra-assisted instruction represents a potentially promising, accessible, and theoretically grounded strategy that warrants further exploration for improving Grade 11 students' measurement achievement in secondary schools with similar characteristics. Persistent difficulties with three-dimensional visualization among Caribbean students, documented in successive CSEC examination reports, represent precisely the challenges that GeoGebra's dynamic geometry environment is designed to address. Teachers and policymakers in Guyana and across the region may find it worthwhile to cautiously explore GeoGebra as one possible instructional tool, while remaining mindful of the preliminary nature of the available evidence. The convergence of international research evidence, theoretical rationale, and the present study's contextually situated findings may provide a sufficiently tentative foundation for informed experimentation and continued empirical investigation. Larger and more methodologically diverse studies will ultimately determine the full scope and durability of GeoGebra's potential benefits for Caribbean mathematics education, and this study tentatively suggests that the question merits further inquiry and that the answer remains worth pursuing.

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