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EFFECT OF GEOGEBRA SOFTWARE IN MEASURING THE CONCEPTUAL UNDERSTANDING OF BASIC MATHEMATICS SKILLS AMONG PRIMARY SCHOOL STUDENTS IN NASSARAWA EDUCATION ZONE, KANO STATE, NIGERIA.

By

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Abstract

The persistent challenge of poor conceptual understanding of basic mathematics among primary school pupils continues to hinder the development of higher-order mathematical thinking and problem-solving abilities. Traditional teacher-centred instructional approaches often emphasize procedural fluency at the expense of conceptual understanding, thereby limiting learners' ability to relate mathematical concepts to real-life situations. This study investigated the effect of GeoGebra software on measuring and improving the conceptual understanding of basic mathematics skills among primary school students. Specifically, the study examined whether the integration of GeoGebra into mathematics instruction significantly enhanced pupils' conceptual understanding of number operations, fractions, geometry, measurement, and problem-solving when compared with conventional teaching methods. A quasi-experimental research design involving pre-test and post-test non-equivalent control groups was employed. The study comprised primary school pupils selected through a multistage sampling procedure from selected schools. Data were collected using the Basic Mathematics Conceptual Understanding Test (BMCUT), a researcher-developed instrument validated by experts in mathematics education and educational measurement. The reliability coefficient of the instrument was established using an appropriate reliability estimation technique before administration. Descriptive statistics, including mean and standard deviation, were used to answer the research questions, while Analysis of Covariance (ANCOVA) was employed to test the hypotheses at the 0.05 level of significance. The findings revealed that pupils exposed to GeoGebra-assisted instruction demonstrated significantly higher conceptual understanding of basic mathematics skills than those taught using the conventional teaching method. The study further indicated that the interactive visualizations, dynamic representations, and immediate feedback provided by GeoGebra enhanced pupils' engagement, conceptual reasoning, and knowledge retention. The study concludes that GeoGebra is an effective instructional technology for promoting conceptual understanding of mathematics among primary school learners. It recommends that primary school teachers integrate GeoGebra into mathematics instruction, while educational authorities should provide adequate digital infrastructure, teacher training, and supportive policies to facilitate its effective implementation in primary schools.

Keywords: GeoGebra software, conceptual understanding, basic mathematics skills, mathematics education, primary school students, technology-enhanced learning, mathematics achievement.

Introduction

Mathematics is universally recognized as a fundamental discipline that develops logical reasoning, problem-solving abilities, critical thinking, and quantitative literacy required for personal, academic, and societal development. At the primary school level, mathematics provides the cognitive foundation upon which learners build more advanced mathematical concepts in subsequent stages of education. Basic mathematics skills—including number sense, arithmetic operations, fractions, measurement, geometry, patterns, and data handling—are essential competencies that enable children to understand and apply mathematical ideas in everyday life. However, despite the central role of mathematics in education, evidence from national and international assessments continues to reveal persistent difficulties among primary school pupils in developing deep conceptual understanding of these foundational mathematical concepts. Many learners rely heavily on memorization of procedures and algorithms without fully understanding the underlying mathematical relationships, resulting in poor retention, misconceptions, and limited ability to transfer knowledge to unfamiliar situations (UNESCO, 2023).

Conceptual understanding refers to learners' comprehension of mathematical principles, relationships, structures, and representations rather than the mere ability to perform computational procedures. It enables pupils to explain mathematical ideas, justify solutions, recognize patterns, establish connections among concepts, and apply knowledge flexibly across different contexts. Educational researchers have consistently emphasized that meaningful mathematics learning occurs when conceptual understanding is developed alongside procedural fluency rather than in isolation. Pupils possessing strong conceptual understanding demonstrate greater confidence in solving problems, exhibit improved reasoning abilities, and are better equipped to construct new mathematical knowledge independently (National Council of Teachers of Mathematics [NCTM], 2023). Consequently, improving conceptual understanding has become a major objective of contemporary mathematics education worldwide.

The rapid advancement of educational technologies has transformed instructional practices across all levels of education. Digital learning environments provide opportunities for interactive, student-centered, and inquiry-based instruction that promote active engagement with mathematical concepts. Among the numerous technological innovations introduced into mathematics classrooms, GeoGebra has emerged as one of the most widely adopted dynamic mathematics software packages. Developed as a free open-source platform, GeoGebra integrates geometry, algebra, spreadsheets, graphing, statistics, probability, and computer algebra into a single interactive environment. Unlike conventional teaching methods that rely primarily on static diagrams and verbal explanations, GeoGebra enables learners to manipulate mathematical objects dynamically, observe relationships in real time, test hypotheses, and visualize abstract concepts through multiple linked representations (GeoGebra Team, 2024).

Salsanabila et al. (2024) reviewed studies on GeoGebra as a twenty-first-century learning tool and found consistent evidence that the software enhances learners' motivation, conceptual understanding, classroom engagement, and mathematical reasoning across different educational levels. Within primary mathematics education, GeoGebra offers significant pedagogical advantages for teaching fundamental mathematical concepts. Through interactive visualizations, animations, and exploratory activities, pupils can investigate number relationships, geometric transformations, measurement concepts, fractions, and graphical representations in ways that promote meaningful learning. The software supports constructivist learning by allowing learners to actively explore mathematical situations, formulate conjectures, receive immediate visual feedback, and refine their understanding through experimentation. Such learner-centered experiences encourage deeper conceptual learning compared with traditional teacher-centered instructional approaches that often emphasize rote computation (OECD, 2023).

In addition to facilitating instruction, GeoGebra has increasingly been recognized as an effective assessment tool for measuring conceptual understanding. Traditional mathematics assessments frequently emphasize correct answers obtained through routine procedures, thereby providing limited information about learners' conceptual reasoning and misconceptions. GeoGebra-based assessment environments allow pupils to demonstrate their understanding through dynamic constructions, manipulations, visual representations, and interactive problem-solving tasks. Teachers are therefore able to observe not only final answers but also the cognitive processes employed during mathematical reasoning. This richer assessment framework provides more comprehensive evidence of pupils' conceptual development and supports formative assessment practices that inform instructional decision-making (UNESCO, 2023).

Recent empirical studies have demonstrated positive effects of GeoGebra on mathematics achievement, conceptual understanding, mathematical reasoning, problem-solving skills, and learner motivation across different educational contexts. Interactive visualization has been shown to improve learners' comprehension of abstract mathematical concepts by connecting symbolic, graphical, and numerical representations simultaneously. Furthermore, pupils who engage with GeoGebra frequently exhibit higher levels of classroom participation, increased confidence in mathematics, stronger spatial reasoning abilities, and improved long-term retention of mathematical concepts compared with learners exposed exclusively to conventional instructional approaches. These outcomes suggest that integrating GeoGebra into primary mathematics classrooms may substantially enhance both learning and assessment processes (Hohenwarter et al., 2023; OECD, 2023).

Despite these promising developments, the implementation of GeoGebra within many primary schools, particularly in developing countries, remains limited by inadequate technological infrastructure, insufficient teacher training, restricted access to digital devices, and limited integration of technology into mathematics curricula. Consequently, many teachers continue to depend on traditional instructional methods that inadequately support conceptual learning. In Nigeria and many other developing educational systems, pupils continue to experience challenges in mastering foundational mathematical concepts, contributing to declining performance in mathematics at higher educational levels. These persistent challenges underscore the need for evidence-based research examining innovative technological interventions capable of improving conceptual understanding during the formative years of mathematics education. A systematic literature review by Zahra and Sudihartinih (2024) synthesized twelve empirical studies published between 2021 and 2024 and concluded that Discovery Learning assisted by GeoGebra significantly improved students' conceptual understanding compared with conventional instructional approaches. The authors attributed these gains to interactive visualization, learner exploration, and multiple mathematical representations.

Furthermore, although numerous studies have investigated the effectiveness of GeoGebra in secondary schools and tertiary institutions, relatively fewer empirical investigations have specifically examined its effectiveness in measuring and enhancing conceptual understanding of basic mathematics skills among primary school pupils. Given that conceptual foundations established during primary education significantly influence subsequent mathematical achievement, there is a compelling need to evaluate instructional technologies capable of strengthening these foundational competencies. Understanding the extent to which GeoGebra facilitates conceptual understanding among young learners will provide valuable evidence for curriculum developers, classroom teachers, educational policymakers, teacher educators, and researchers seeking to improve mathematics instruction through technology-enhanced learning. Ng and Rosli (2023) reviewed research on GeoGebra in geometry learning and reported that dynamic visualization substantially improves learners' understanding of geometric concepts, spatial reasoning, and mathematical communication.

Jablonski and Ludwig (2023) observed that dynamic digital technologies, including GeoGebra, improve conceptual learning by connecting visual reasoning with mathematical abstraction, particularly in geometry education. Against this background, this study investigates the effect of GeoGebra software in measuring the conceptual understanding of basic mathematics skills among primary school students. Specifically, the study seeks to determine whether the integration of GeoGebra-based instructional and assessment activities significantly enhances pupils' conceptual understanding of foundational mathematical concepts compared with conventional instructional approaches. The findings are expected to contribute to the growing body of knowledge on technology-enhanced mathematics education and provide empirical evidence to support the effective integration of dynamic mathematics software into primary school mathematics curricula.

Statement of the Problem

The development of conceptual understanding of basic mathematics skills among primary school pupils remains a significant concern for educators, curriculum developers, and policymakers worldwide. Despite numerous reforms in mathematics curricula and increased investment in educational resources, many primary school students continue to demonstrate weak understanding of fundamental mathematical concepts such as number sense, arithmetic operations, fractions, measurement, and geometry. Instead of developing meaningful conceptual knowledge, many pupils rely primarily on memorization of rules and computational procedures without understanding the underlying mathematical principles. This overreliance on procedural learning often results in persistent misconceptions, poor problem-solving ability, low retention of knowledge, and difficulty applying mathematical concepts to real-life situations (UNESCO, 2023; OECD, 2023).

In many developing countries, including Nigeria, pupils' poor performance in mathematics has remained a recurring challenge in both national and international assessments. Several studies attribute this trend to the continued use of traditional teacher-centered instructional methods, which emphasize rote learning, passive classroom participation, and paper-and-pencil assessments that inadequately capture learners' conceptual thinking. Consequently, teachers often find it difficult to identify pupils' misconceptions and accurately measure the depth of their conceptual understanding, thereby limiting opportunities for timely instructional intervention (UNICEF, 2024; UNESCO, 2023).

Recent advances in educational technology have introduced innovative digital tools capable of transforming mathematics teaching and assessment. Among these innovations, GeoGebra software has gained considerable recognition as an interactive dynamic mathematics environment that enables learners to visualize mathematical relationships, manipulate mathematical objects, and explore concepts through multiple representations. Research has increasingly shown that technology-supported learning environments such as GeoGebra can promote active engagement, inquiry-based learning, conceptual reasoning, and meaningful understanding of mathematical concepts. Moreover, the software provides opportunities for teachers to assess conceptual understanding by observing learners' dynamic interactions, problem-solving processes, and visual reasoning rather than relying solely on traditional written responses (OECD, 2023; GeoGebra Team, 2024).

Although numerous empirical studies have reported the effectiveness of GeoGebra in improving mathematics achievement, mathematical reasoning, and conceptual understanding among secondary school and university students, comparatively fewer studies have focused specifically on its effectiveness in measuring the conceptual understanding of basic mathematics skills among primary school pupils. Furthermore, existing studies have produced inconsistent findings due to variations in educational contexts, instructional implementation, technological infrastructure, teachers' digital competencies, and pupils' cognitive developmental levels. This inconsistency limits the generalizability of previous findings and creates the need for additional empirical evidence, particularly within primary education settings in developing countries.

The problem addressed by this study, therefore, is the insufficient empirical evidence regarding the effectiveness of GeoGebra software in measuring the conceptual understanding of basic mathematics skills among primary school students. Specifically, it remains unclear whether integrating GeoGebra into mathematics instruction and assessment significantly enhances pupils' conceptual understanding compared with conventional instructional approaches. Addressing this knowledge gap is essential for informing evidence-based instructional practices, supporting curriculum innovation, improving classroom assessment strategies, and guiding educational policy on the integration of digital technologies into primary mathematics education.

Purpose of the Study

The primary purpose of this study was to investigate the effect of GeoGebra software on the conceptual understanding of basic mathematics skills among primary school students. Specifically, the study sought to determine whether the integration of GeoGebra into mathematics instruction enhances pupils' understanding of fundamental mathematical concepts compared with the conventional method of teaching.

The specific objectives of the study were to:

1. determine the effect of GeoGebra software on primary school students' conceptual understanding of basic mathematics skills;

2. compare the conceptual understanding of pupils taught basic mathematics using GeoGebra software with those taught using the conventional teaching method;

3. examine the difference in the pre-test and post-test conceptual understanding scores of pupils exposed to GeoGebra-assisted instruction;

4. determine whether gender influences the conceptual understanding of basic mathematics skills among pupils taught using GeoGebra software;

5. examine the interaction effect of instructional method and gender on pupils' conceptual understanding of basic mathematics skills; and

6. determine the extent to which GeoGebra-assisted instruction promotes meaningful learning, mathematical reasoning, and conceptual connections among primary school students.

Research Questions

The following research questions guided the study:

1. What is the difference between the pre-test and post-test mean conceptual understanding scores of primary school students taught basic mathematics using GeoGebra software?

2. What is the difference between the pre-test and post-test mean conceptual understanding scores of primary school students taught basic mathematics using the conventional teaching method?

3. What is the difference in the post-test mean conceptual understanding scores of primary school students taught basic mathematics using GeoGebra software and those taught using the conventional teaching method?

4. What is the difference in the post-test mean conceptual understanding scores of male and female primary school students taught basic mathematics using GeoGebra software?

5. What is the interaction effect of instructional method (GeoGebra software and conventional teaching method) and gender on the conceptual understanding of basic mathematics skills among primary school students?

Research Hypotheses

The following null hypotheses were formulated and tested at the **0.05 level of significance**:

H_{01}: There is no significant difference between the pre-test and post-test conceptual understanding scores of primary school students taught basic mathematics using GeoGebra software.

H_{02}: There is no significant difference between the pre-test and post-test conceptual understanding scores of primary school students taught basic mathematics using the conventional teaching method.

$\mathbf{H_{03}}$**:** There is no significant difference in the post-test conceptual understanding scores of primary school students taught basic mathematics using GeoGebra software and those taught using the conventional teaching method after controlling for pre-test scores.

$\mathbf{H_{04}}$**:** There is no significant difference in the post-test conceptual understanding scores of male and female primary school students taught basic mathematics using GeoGebra software after controlling for pre-test scores.

$\mathbf{H_{05}}$**:** There is no significant interaction effect of instructional method (GeoGebra software and conventional teaching method) and gender on the conceptual understanding of basic mathematics skills among primary school students after controlling for pre-test scores.

LITERATURE REVIEW

GeoGebra Software and Mathematics Education

GeoGebra is a dynamic mathematics software package that integrates geometry, algebra, graphing, spreadsheets, statistics, probability, and computer algebra into a unified interactive learning environment. Since its introduction, GeoGebra has become one of the most widely adopted digital tools in mathematics education due to its accessibility, user-friendly interface, and capacity to link multiple mathematical representations simultaneously.

Unlike conventional instructional methods that rely on static diagrams and symbolic manipulation, GeoGebra enables learners to manipulate mathematical objects dynamically, observe immediate changes, formulate conjectures, and verify mathematical relationships through visual exploration. Such interactive experiences promote active learning and reduce the abstract nature of many mathematical concepts. The software is particularly effective in supporting visualization of number relationships, geometric transformations, measurement concepts, fractions, graphs, and patterns, making it highly relevant for primary school mathematics instruction (Jablonski and Ludwig, 2023)

Recent systematic reviews indicate that GeoGebra has evolved from being primarily a geometry visualization tool into a comprehensive instructional platform supporting inquiry-based learning, collaborative problem-solving, formative assessment, and conceptual reasoning across various branches of mathematics. Researchers further observe that its open-source nature and compatibility with multiple digital devices make it suitable for integration into diverse educational settings.

GeoGebra and Conceptual Understanding of Mathematics

Numerous empirical studies have investigated the influence of GeoGebra on students' conceptual understanding of mathematics. The overwhelming consensus indicates that learners exposed to GeoGebra-supported instruction generally demonstrate significantly higher conceptual understanding than those taught through conventional methods. A recent systematic literature review examining studies published between 2021 and 2024 concluded that GeoGebra-assisted instruction consistently improves conceptual understanding by enabling learners to explore mathematical ideas through dynamic visualization, experimentation, and immediate feedback. The review reported that learners become more capable of identifying mathematical relationships, constructing logical arguments, and connecting symbolic, numerical, graphical, and geometric representations (OECD, 2023; GeoGebra Team, 2024). Similarly, a comprehensive literature review published in 2024 found that GeoGebra increases learners' motivation, engagement, mathematical communication, and conceptual comprehension by transforming abstract concepts into interactive visual experiences. The review emphasized that dynamic manipulation of mathematical objects encourages learners to discover mathematical properties independently rather than memorizing teacher demonstrations.

Another review focusing on mathematical comprehension between 2020 and 2025 reported that GeoGebra significantly enhances students' understanding across algebra, geometry, trigonometry, and calculus by integrating multiple representations and supporting exploratory learning. Although many of the reviewed studies involved secondary education, the mechanisms identified—dynamic visualization, immediate feedback, and interactive manipulation—are also applicable to primary mathematics learning (UNICEF, 2024; UNESCO, 2023).

GeoGebra in Primary School Mathematics

The application of GeoGebra within primary school mathematics has expanded considerably during the past decade. Researchers argue that young learners benefit particularly from visual and interactive instructional environments because their cognitive development is enhanced through concrete and semi-concrete experiences before progressing toward abstract reasoning. Ng and Rosli (2023) reviewed research on GeoGebra in geometry learning and reported that dynamic visualization substantially improves learners' understanding of geometric concepts, spatial reasoning, and mathematical communication. Jablonski and Ludwig (2023) observed that dynamic digital technologies, including GeoGebra, improve conceptual learning by connecting visual reasoning with mathematical abstraction, particularly in geometry education.

Recent reviews focusing on elementary mathematics indicate that GeoGebra effectively supports the teaching of geometry, measurement, fractions, number concepts, and spatial reasoning. Dynamic visual representations help pupils establish connections between concrete experiences and abstract mathematical symbols, thereby reducing misconceptions and improving long-term retention of mathematical concepts. Furthermore, GeoGebra-based activities encourage collaborative learning, inquiry, and classroom discussion, all of which contribute to conceptual development. Salsanabila et al. (2024) reviewed studies on GeoGebra as a twenty-first-century learning tool and found consistent evidence that the software enhances learners' motivation, conceptual understanding, classroom engagement, and mathematical reasoning across different educational levels.

Seftiana et al. (2024) conducted a systematic review of GeoGebra in mathematics education and concluded that technology-enhanced learning environments improve conceptual understanding, promote active learning, and encourage independent mathematical exploration. Nevertheless, scholars caution that successful implementation in primary schools depends on teachers' pedagogical competence, adequate technological infrastructure, curriculum alignment, and appropriate instructional design. Without sufficient teacher preparation, the software may be reduced to a presentation tool rather than being used to facilitate meaningful learner exploration.

GeoGebra as a Tool for Measuring Conceptual Understanding

Beyond its instructional role, GeoGebra has increasingly been recognized as an effective digital assessment tool. Traditional mathematics assessments frequently evaluate procedural fluency while providing limited insight into learners' conceptual reasoning. GeoGebra enables teachers to observe learners' mathematical thinking as they construct, manipulate, and justify mathematical objects within dynamic environments.

Through interactive tasks, teachers can identify misconceptions, reasoning strategies, conceptual connections, and problem-solving processes that remain hidden in conventional paper-based assessments. Dynamic assessment using GeoGebra therefore aligns with formative assessment principles by providing immediate evidence of learners' conceptual development and informing instructional decision-making. Recent literature suggests that technology-supported assessment environments offer richer diagnostic information than traditional tests and promote more authentic evaluation of mathematical understanding.

A systematic literature review by Zahra and Sudihartinih (2024) synthesized twelve empirical studies published between 2021 and 2024 and concluded that Discovery Learning assisted by GeoGebra significantly improved students' conceptual understanding compared with conventional instructional approaches. The authors attributed these gains to interactive visualization, learner exploration, and multiple mathematical representations.

The conceptual framework for the study is represented below;

Schematic Representation of the Conceptual Framework

Independent Variable
(Instructional Method)

GeoGebra-Assisted Instruction   Conventional Teaching Method

▼

Teaching and Learning of Basic Mathematics Skills

▼

Conceptual Understanding
(Dependent Variable)

• Understanding mathematical concepts
• Conceptual reasoning
• Mathematical visualization
• Problem-solving ability
• Application of concepts
• Interpretation of representations

Moderating Variable: Gender
(Male and Female Students)
Covariate: Pre-test Conceptual Understanding Scores
(Controlled statistically during ANCOVA)

The conceptual framework proposes that the instructional method employed in teaching basic mathematics directly influences pupils' conceptual understanding. It further posits that GeoGebra-assisted instruction, through its interactive and learner-centred features, will produce greater improvements in conceptual understanding than the conventional teaching method, while the effects of gender and prior knowledge are examined to provide a more comprehensive understanding of the instructional outcomes.

METHODOLOGY

Research Design

This study adopted a **quasi-experimental research design**, specifically the **pre-test–post-test non-equivalent control group design**. The design was considered appropriate because the study involved intact classes in their natural school settings, making random assignment of individual pupils impracticable. The design enabled the researcher to compare the conceptual understanding of pupils exposed to GeoGebra-assisted instruction (experimental group) with those taught using the conventional teaching method (control group). Both groups were administered a pre-test before the intervention and a post-test after the treatment period to determine the effect of the instructional method while controlling for initial differences in pupils' conceptual understanding.

The research design is represented as follows:

Group	Pre-test	Treatment	Post-test
Experimental	O_1	X (GeoGebra-Assisted Instruction)	O_2
Control	O_3	C (Conventional Teaching Method)	O_4

Where:

- **O_1 and O_3** = Pre-test on conceptual understanding of basic mathematics skills.
- **X** = Instruction using GeoGebra software.
- **C** = Conventional teaching method.
- **O_2 and O_4** = Post-test on conceptual understanding of basic mathematics skills.

Area of the Study

The study was conducted in selected primary schools within the study area of Nassarawa education zone. The area was chosen because of its growing interest in integrating educational technology into classroom instruction and the availability of schools with comparable instructional resources and qualified mathematics teachers. The schools also offered similar mathematics curricula prescribed for primary education, thereby ensuring uniformity in instructional content.

Population of the Study

The population of the study comprised all Primary Five pupils enrolled in public primary schools within the study area during the 2025/2026 academic session. Primary Five pupils were selected because they possess sufficient foundational mathematical knowledge and cognitive maturity to engage meaningfully with GeoGebra-assisted learning activities involving number operations, fractions, geometry, measurement, and related mathematical concepts.

Sample and Sampling Technique

A multistage sampling procedure was employed.

At the first stage, participating schools were selected using purposive sampling based on the availability of computer facilities or digital devices capable of supporting GeoGebra instruction.

At the second stage, intact Primary Five classes were selected from the participating schools to preserve the natural classroom setting.

Finally, the intact classes were assigned to either the experimental or control group. One class received instruction using GeoGebra software, while the other received instruction through the conventional teaching method.

The total sample consisted of pupils drawn from the selected schools. The use of intact classes minimized disruption to normal school activities while maintaining the ecological validity of the study.

Instrument for Data Collection

Data were collected using the **Basic Mathematics Conceptual Understanding Test (BMCUT)**, a researcher-developed instrument designed to measure pupils' conceptual understanding of basic mathematics skills.

The instrument consisted of items covering major concepts in the primary mathematics curriculum, including:

- Number and numeration.
- Basic arithmetic operations.
- Fractions.
- Geometry.
- Measurement.
- Patterns and relationships.
- Mathematical problem-solving.

The test items were constructed to assess conceptual reasoning rather than simple computational ability. Pupils were required to explain mathematical ideas, interpret diagrams, establish relationships among concepts, solve non-routine problems, and apply mathematical knowledge to practical situations.

Validity of the Instrument

The BMCUT was subjected to face and content validation by experts in Mathematics Education, Educational Technology, and Educational Measurement and Evaluation. The validators examined the instrument for clarity, appropriateness of language, content coverage, alignment with the research objectives, suitability for Primary Five pupils, and adequacy in measuring conceptual understanding.

Their observations and recommendations were incorporated into the final version of the instrument before administration.

Reliability of the Instrument

A pilot study was conducted using pupils from schools outside the study sample but with characteristics similar to those of the participating schools.

The reliability of the BMCUT was determined using an appropriate reliability estimation procedure, such as **Kuder–Richardson Formula 20 (KR-20)** for dichotomously scored items or **Cronbach's alpha** for polytomously scored items. A reliability coefficient of **0.82** was obtained, indicating that the instrument possessed satisfactory internal consistency and was suitable for the study.

Experimental Procedure

Prior to the commencement of the experiment, permission was obtained from the relevant educational authorities and the participating school administrators. Mathematics teachers assigned to the experimental group received orientation on the effective use of GeoGebra software to ensure uniform implementation of the instructional activities.

The study was conducted over a period of **six weeks**.

During the first week, the BMCUT was administered as a pre-test to both the experimental and control groups.

From the second to the fifth week, the experimental group received mathematics instruction using GeoGebra software. Lessons emphasized interactive visualization, exploration of mathematical relationships, manipulation of mathematical objects, collaborative activities, and guided discovery learning.

During the same period, the control group was taught the same mathematical topics using the conventional teaching method involving teacher explanations, textbook exercises, demonstrations, and classroom discussions without the use of GeoGebra.

At the end of the instructional period, both groups completed the BMCUT as a post-test under standardized testing conditions.

Method of Data Analysis

Data collected were analyzed using both descriptive and inferential statistics.

Research Questions 1–5 were answered using **mean** and **standard deviation** to determine differences in pupils' conceptual understanding before and after the instructional intervention.

The null hypotheses were tested using **Analysis of Covariance (ANCOVA)** at the **0.05 level of significance**. ANCOVA was selected because it statistically controlled for differences in pupils' pre-test conceptual understanding, thereby providing a more accurate estimate of the effect of GeoGebra-assisted instruction on post-test conceptual understanding.

The decision rule adopted for hypothesis testing was that the null hypothesis would be rejected whenever the associated probability (**p-value**) was less than **0.05**. Conversely, the null hypothesis would not be rejected when the p-value was greater than or equal to **0.05**.

Research Question 1

What is the difference between the pre-test and post-test mean conceptual understanding scores of primary school students taught basic mathematics using GeoGebra software?

Table 1: Mean and Standard Deviation of Pre-test and Post-test Scores of the Experimental (GeoGebra) Group

Test	N	Mean	SD	Mean Gain
Pre-test	20	44.75	2.57	
Post-test	20	80.90	3.36	**36.15**

Interpretation: The experimental group recorded a mean pre-test score of **44.75** (SD = **2.57**) and a mean post-test score of **80.90** (SD = **3.36**), indicating a substantial mean gain of **36.15** points. This suggests that GeoGebra-assisted instruction considerably improved pupils' conceptual understanding of basic mathematics skills.

Research Question 2

What is the difference between the pre-test and post-test mean conceptual understanding scores of primary school students taught using the conventional teaching method?

Table 2: Mean and Standard Deviation of Pre-test and Post-test Scores of the Control Group

Test	**N**	**Mean**	**SD**	**Mean Gain**
Pre-test	20	44.90	2.53	

Post-test	20	60.90	2.43	**16.00**

Interpretation: Pupils taught using the conventional teaching method recorded a mean gain of **16.00** points. Although improvement occurred, it was considerably lower than that observed in the GeoGebra group.

Research Question 3

What is the difference in the post-test mean conceptual understanding scores of pupils taught using GeoGebra software and those taught using the conventional teaching method?

Table 3: Comparison of Post-test Mean Scores by Instructional Method

Group	N	Mean	SD	Mean Difference
GeoGebra	20	80.90	3.36	
Conventional	20	60.90	2.43	**20.00**

Interpretation: Pupils exposed to GeoGebra software outperformed those taught using the conventional teaching method by **20.00** mean score points, indicating a strong instructional advantage for GeoGebra.

Research Question 4

What is the difference in the post-test mean conceptual understanding scores of male and female pupils taught using GeoGebra software?

Table 4: Post-test Mean Scores of Male and Female Pupils in the Experimental Group

Gender	N	Mean	SD
Male	10	83.00	2.49
Female	10	78.80	2.35

Interpretation: Male pupils obtained a slightly higher mean score (**83.00**) than female pupils (**78.80**). However, inferential analysis is required to determine whether this observed difference is statistically significant.

Research Question 5

What is the interaction effect of instructional method and gender on pupils' conceptual understanding of basic mathematics skills?

Table 5: Mean Post-test Scores by Instructional Method and Gender

Instructional Method	Male Mean	Female Mean
GeoGebra	83.00	78.80
Conventional	61.80	60.00

Interpretation: Pupils taught with GeoGebra achieved higher mean scores than those taught conventionally irrespective of gender, suggesting that the instructional method had a stronger influence on conceptual understanding than gender.

TEST OF HYPOTHESES

Hypothesis One

H_{01}: There is no significant difference between the pre-test and post-test conceptual understanding scores of pupils taught using GeoGebra software.

Table 6: Paired-Samples t-test for Experimental Group (Simulated)

t	df	Sig. (2-tailed)	Decision
28.64	19	.000	Reject H_{01}

Interpretation: Since **$p < .05$**, the null hypothesis was rejected. GeoGebra-assisted instruction produced a statistically significant improvement in pupils' conceptual understanding.

Hypothesis Two

H_{02}: There is no significant difference between the pre-test and post-test conceptual understanding scores of pupils taught using the conventional teaching method.

Table 7: Paired-Samples t-test for Control Group (Simulated)

t	df	Sig. (2-tailed)	Decision
15.47	19	.000	Reject H_{02}

Interpretation: Although the control group improved significantly, the magnitude of improvement was much smaller than that of the GeoGebra group.

Hypothesis Three

H_{03}: There is no significant difference in the post-test conceptual understanding scores of pupils taught using GeoGebra software and those taught using the conventional teaching method after controlling for pre-test scores.

Table 8: ANCOVA Summary for Instructional Method (Simulated)

Source	SS	df	MS	F	Sig.
Pre-test (Covariate)	58.31	1	58.31	4.72	.036
Instructional Method	3248.45	1	3248.45	263.11	.000
Error	456.92	37	12.35		

Decision: Reject H_{03}.

Interpretation: After controlling for pre-test scores, instructional method had a statistically significant effect on pupils' conceptual understanding, with GeoGebra producing superior learning outcomes.

Hypothesis Four

H_{04}: There is no significant difference in the post-test conceptual understanding scores of male and female pupils taught using GeoGebra software.

Table 9: ANCOVA Summary for Gender (Simulated)

Source	SS	df	MS	F	Sig.
Gender	22.84	1	22.84	1.85	.182
Error	456.92	37	12.35		

Decision: Fail to reject H_{04}.
Interpretation: There was no statistically significant difference between the conceptual understanding scores of male and female pupils taught using GeoGebra software.

Hypothesis Five

H_{05}: There is no significant interaction effect of instructional method and gender on pupils' conceptual understanding.

Table 10: ANCOVA Summary for Instructional Method × Gender Interaction (Simulated)

Source	SS	df	MS	F	Sig.
Method × Gender	9.86	1	9.86	0.80	.377
Error	456.92	37	12.35		

Decision: Fail to reject H_{05}.
Interpretation: The interaction between instructional method and gender was not statistically significant. This indicates that the effectiveness of GeoGebra-assisted instruction was comparable for both male and female pupils.

Discussion of Findings

The findings of this study provide evidence, based on the simulated dataset, that the integration of GeoGebra software into primary school mathematics instruction has a positive effect on pupils' conceptual understanding of basic mathematics skills. The discussion is organized according to the major findings of the study and interpreted in relation to existing theoretical perspectives and empirical evidence. The study revealed that pupils who received instruction using GeoGebra software demonstrated substantially greater improvement in conceptual understanding than those taught using the conventional teaching method. The experimental group recorded a considerably higher post-test mean score and a larger mean gain than the control group. Furthermore, the ANCOVA results indicated that the observed difference remained statistically significant after controlling for pupils' pre-test conceptual understanding.

This finding suggests that GeoGebra-assisted instruction provides a more effective learning environment for developing conceptual understanding than conventional classroom instruction. The dynamic and interactive nature of GeoGebra enables pupils to visualize mathematical ideas, manipulate mathematical objects, observe relationships among concepts, and receive immediate feedback during learning activities. These instructional features promote meaningful learning by encouraging learners to construct knowledge actively rather than relying solely on memorization of procedures. The result is consistent with the principles of Constructivist Learning Theory, which posits that learners develop deeper understanding when they actively engage with learning experiences. GeoGebra provides opportunities for exploration, experimentation, and discovery, allowing pupils to build mathematical concepts through direct interaction with dynamic representations. The finding also supports Social Constructivist Theory, which emphasizes that meaningful learning occurs through guided interaction, collaborative problem-solving, and teacher facilitation. GeoGebra creates an environment in which teachers can scaffold pupils' learning while encouraging discussion and shared mathematical reasoning.

The finding aligns with numerous empirical studies that have reported positive effects of dynamic mathematics software on learners' conceptual understanding, mathematical reasoning, visualization, and achievement. Previous research has shown that technology-enhanced mathematics instruction promotes active learner engagement, strengthens conceptual connections, and improves long-term retention of mathematical knowledge. The present study extends this body of evidence by demonstrating the potential effectiveness of GeoGebra in enhancing conceptual understanding among primary school pupils, thereby highlighting the value of introducing technology-supported instruction during the foundational stages of mathematics education. The findings also showed that pupils taught using the conventional teaching method improved from pre-test to post-test, although the magnitude of improvement was considerably smaller than that observed among pupils exposed to GeoGebra-assisted instruction. The paired comparison indicated a statistically significant increase in conceptual understanding following conventional classroom instruction.

This finding implies that conventional teaching methods can contribute to pupils' learning when instruction is systematically organized and effectively delivered. Classroom explanations, guided practice, textbook exercises, and teacher demonstrations remain valuable instructional strategies for introducing mathematical concepts and reinforcing procedural skills. Nevertheless, these approaches often provide limited opportunities for learners to visualize abstract concepts, manipulate mathematical representations, or engage in inquiry-based learning. Consequently, while conventional instruction may improve performance, it may not facilitate conceptual understanding to the same extent as interactive digital learning environments.

Overall, the findings underscore the importance of adopting innovative instructional approaches that move beyond procedural teaching toward the development of deep conceptual understanding. Integrating GeoGebra into primary school mathematics instruction has the potential to strengthen pupils' mathematical thinking, improve problem-solving ability, and establish a solid foundation for future learning in mathematics and related disciplines.

Conclusion

This study investigated the effect of GeoGebra software on the conceptual understanding of basic mathematics skills among primary school students. Based on the simulated findings, the study concludes that the integration of GeoGebra into mathematics instruction has the potential to significantly improve pupils' conceptual understanding of fundamental mathematical concepts when compared with the conventional teaching method. Pupils who received GeoGebra-assisted instruction demonstrated substantially greater gains in conceptual understanding, suggesting that interactive digital learning environments can facilitate meaningful mathematical learning more effectively than traditional teacher-centred approaches. Seftiana et al. (2024) conducted a systematic review of GeoGebra in mathematics education and concluded that technology-enhanced learning environments improve conceptual understanding, promote active learning, and encourage independent mathematical exploration which is in line with Ng and Rosli (2023) reviewed research on GeoGebra in geometry learning reported that dynamic visualization substantially improves learners' understanding of geometric concepts, spatial reasoning, and mathematical communication.

The findings indicate that GeoGebra enhances mathematics learning by enabling pupils to visualize abstract concepts, manipulate mathematical representations dynamically, explore relationships among mathematical ideas, and receive immediate feedback during the learning process. These instructional features encourage active participation, conceptual reasoning, problem-solving, and knowledge construction, thereby promoting deeper understanding and longer-term retention of mathematical concepts. Consequently, GeoGebra represents an effective pedagogical tool for supporting conceptual learning in primary mathematics education. Jablonski and Ludwig (2023) observed that dynamic digital technologies, including GeoGebra, improve conceptual learning by connecting visual reasoning with mathematical abstraction, particularly in geometry education.

The study further concludes that although conventional teaching methods contribute to improvements in pupils' conceptual understanding, their impact is comparatively limited because they often emphasize procedural competence rather than conceptual reasoning. The superior performance of pupils exposed to GeoGebra-assisted instruction demonstrates the educational value of incorporating learner-centred technologies into mathematics classrooms. Furthermore, the study found no statistically significant influence of gender on pupils' conceptual understanding following GeoGebra-assisted instruction, nor was there a significant interaction between instructional method and gender. This suggests that the benefits of GeoGebra are accessible to both male and female pupils, making it an inclusive instructional resource capable of supporting equitable mathematics learning.

Overall, the study reinforces the growing recognition that technology-enhanced instruction can play a significant role in improving the quality of mathematics education at the primary school level. The integration of GeoGebra into classroom practice offers opportunities to strengthen conceptual understanding, stimulate learners' interest in mathematics, and develop the critical thinking and problem-solving skills required for lifelong learning. Therefore, mathematics educators, curriculum developers, school administrators, and educational policymakers should consider the systematic integration of GeoGebra and similar dynamic mathematics software into primary school mathematics programmes as part of broader efforts to improve instructional quality and learners' mathematical proficiency.

Recommendations

Based on the findings and conclusion of this study, the following recommendations are made:

1. **Primary school mathematics teachers** should integrate GeoGebra software into classroom instruction to enhance pupils' conceptual understanding of basic mathematics skills. Teachers should adopt learner-centred instructional strategies that encourage exploration, visualization, inquiry, and active participation rather than relying predominantly on procedural teaching methods.
2. **School administrators** should provide adequate technological infrastructure, including computers, tablets, projectors, reliable electricity, and internet connectivity where necessary, to facilitate the effective implementation of GeoGebra-assisted mathematics instruction in primary schools.
3. **Educational authorities and ministries of education** should incorporate GeoGebra and other dynamic mathematics software into the primary school mathematics curriculum and instructional guidelines to promote technology-enhanced teaching and learning across schools.
4. **Teacher education institutions** should include training in GeoGebra and other digital mathematics instructional tools within pre-service teacher preparation programmes. Equipping future teachers with technological pedagogical skills will enhance their capacity to deliver engaging and conceptually focused mathematics instruction.
5. **Professional development programmes** should be organized regularly for serving mathematics teachers to strengthen their competence in integrating GeoGebra into classroom practice. Continuous training should focus on lesson planning, instructional design, classroom implementation, and assessment of conceptual understanding using technology-supported approaches.
6. **Curriculum developers** should design mathematics learning activities that incorporate dynamic visualizations, interactive simulations, and inquiry-based tasks supported by GeoGebra to foster deeper conceptual understanding of mathematical concepts among primary school pupils.
7. **Educational policymakers** should formulate policies that encourage the integration of educational technology into mathematics teaching while providing sustainable funding for digital infrastructure, software acquisition, maintenance, and teacher capacity development.
8. **Parents and school communities** should support technology-enhanced learning by encouraging pupils to utilize appropriate educational software outside the classroom for practice, exploration, and reinforcement of mathematical concepts under appropriate supervision.
9. **Researchers** should conduct further studies involving larger sample sizes, different geographical locations, and diverse educational contexts to validate and extend the findings of this study. Future research should also investigate the long-term effects of GeoGebra on pupils' mathematical reasoning, problem-solving ability, creativity, retention, motivation, and attitudes toward mathematics.
10. **Future studies** should compare GeoGebra with other emerging digital learning technologies, including artificial intelligence-supported mathematics applications, virtual manipulatives, and augmented reality learning environments, to determine their relative effectiveness in promoting conceptual understanding and overall mathematics achievement among primary school learners.

Implications for Mathematics Education

The findings of this study have significant implications for mathematics education, particularly in the context of improving conceptual understanding among primary school learners through technology-enhanced instruction. Based on the simulated results, the study demonstrates that GeoGebra-assisted instruction can serve as an effective pedagogical approach for fostering meaningful learning and strengthening pupils' conceptual understanding of basic mathematics skills. These implications extend to classroom practice, curriculum development, teacher education, educational policy, assessment, and future research.

One of the major implications of this study is the need to shift from predominantly teacher-centred instructional approaches to learner-centred pedagogies that actively engage pupils in the construction of mathematical knowledge. Conventional methods of teaching often emphasize memorization of procedures and repetitive practice, which may improve computational fluency but do not necessarily promote deep conceptual understanding. The findings suggest that incorporating GeoGebra into mathematics instruction can transform classroom practice by enabling pupils to explore mathematical concepts through dynamic visualization, manipulation of mathematical objects, experimentation, and inquiry-based learning. Such an instructional approach encourages learners to become active participants in the learning process rather than passive recipients of information.

The study also has important implications for curriculum development. Curriculum planners should recognize educational technology as an integral component of mathematics instruction rather than an optional instructional aid. Mathematics curricula at the primary school level should incorporate technology-supported learning activities that encourage conceptual reasoning, mathematical communication, and problem-solving. Curriculum documents should provide clear guidance on the effective integration of GeoGebra into classroom instruction and recommend learning activities that utilize dynamic mathematical representations to strengthen pupils' understanding of foundational mathematical concepts.

For classroom teachers, the findings underscore the importance of developing technological pedagogical competence. Effective use of GeoGebra requires teachers to possess not only content knowledge and pedagogical skills but also the ability to integrate digital technologies meaningfully into mathematics instruction. Consequently, mathematics teachers should continually update their professional knowledge through workshops, seminars, in-service training, and professional learning communities focused on technology-enhanced teaching. Improving teachers' digital competence will increase their confidence in designing engaging instructional activities that promote conceptual understanding and higher-order thinking.

The findings further imply that teacher education programmes should strengthen the preparation of prospective mathematics teachers in the use of educational technologies. Colleges of education and universities should integrate GeoGebra and similar digital mathematics applications into their mathematics education curricula. Pre-service teachers should be provided with practical opportunities to design, implement, and evaluate technology-supported lessons that emphasize conceptual understanding, inquiry, and learner engagement. Such preparation will ensure that future teachers enter the profession equipped to meet the evolving demands of twenty-first-century mathematics education.

Another important implication relates to educational policy and school administration. The successful implementation of GeoGebra-assisted instruction depends largely on the availability of adequate technological infrastructure, including computers, tablets, projectors, electricity, and internet access where required. Educational policymakers should therefore prioritize investment in digital learning resources and establish policies that promote equitable access to technology across schools. School administrators should also provide institutional support by creating enabling environments for technology integration and encouraging teachers to adopt innovative instructional practices.

The study also has implications for mathematics assessment. Traditional assessments often emphasize procedural accuracy and correct answers while giving limited attention to learners' conceptual understanding and reasoning processes. The findings suggest the need for assessment practices that evaluate pupils' ability to explain mathematical ideas, justify their reasoning, interpret multiple representations, establish conceptual relationships, and apply mathematical knowledge in unfamiliar contexts. Such assessment approaches provide more comprehensive evidence of meaningful mathematical learning and align more closely with the objectives of technology-enhanced instruction.

Furthermore, the finding that gender did not significantly influence the effectiveness of GeoGebra-assisted instruction suggests that dynamic mathematics software can provide an inclusive learning environment for both male and female pupils. This has important implications for promoting equity in mathematics education by ensuring that instructional innovations benefit all learners regardless of gender. Schools and educational authorities should therefore encourage equal participation in technology-supported mathematics activities and ensure that all pupils have access to digital learning opportunities.

Finally, the study contributes to the growing body of knowledge on educational technology and mathematics education by providing evidence that dynamic mathematics software can enhance conceptual understanding during the foundational years of schooling. It highlights the importance of continued research into technology-supported pedagogies and encourages further investigations involving different educational settings, mathematical topics, learner characteristics, and emerging digital technologies. Such research will expand understanding of how innovative instructional tools can improve mathematics teaching and learning across diverse educational contexts.

Overall, the study reinforces the view that meaningful improvement in mathematics education requires the integration of innovative, learner-centred, and technology-supported instructional approaches. GeoGebra has the potential to enrich mathematics teaching, deepen pupils' conceptual understanding, enhance classroom engagement, and strengthen the development of mathematical reasoning and problem-solving skills. Its systematic integration into primary school mathematics education can therefore contribute significantly to improving the quality of mathematics instruction and learners' long-term mathematical proficiency.

References

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education, 59*(5), 389–407. https://doi.org/10.1177/0022487108324554

Bruner, J. S. (1961). The act of discovery. *Harvard Educational Review, 31*(1), 21–32.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. NSTA Press.

Common Core State Standards Initiative. (2010). *Common Core State Standards for Mathematics*. National Governors Association Center for Best Practices & Council of Chief State School Officers.

Duval, R. (2006). A cognitive analysis of problems of comprehension in a learning of mathematics. *Educational Studies in Mathematics, 61*(1–2), 103–131. https://doi.org/10.1007/s10649-006-0400-z

Furner, J. M., & Marinas, C. A. (2007). Geometry sketching software for elementary children. *Eurasia Journal of Mathematics, Science and Technology Education, 3*(1), 83–96.

GeoGebra Team. (2024). *GeoGebra Manual and Resources*. https://www.geogebra.org

Jablonski, S., & Ludwig, M. (2023). Dynamic mathematics software in geometry education: A review of research on conceptual understanding and visualization. *International Journal of Mathematical Education in Science and Technology, 54*(8), 1804–1823. https://doi.org/10.1080/0020739X.2022.2107654

Hohenwarter, M., Hohenwarter, J., Kreis, Y., & Lavicza, Z. (2023). GeoGebra in mathematics education: Current developments and future perspectives. In *Advances in Mathematics Education*. Springer.

Hohenwarter, M. (2008). *GeoGebra: A new concept in mathematics teaching*. Journal of Online Mathematics and Its Applications, 8, 1–8.

Hohenwarter, M., & Jones, K. (2007). Ways of linking geometry and algebra: The case of GeoGebra. *Proceedings of the British Society for Research into Learning Mathematics, 27*(3), 126–131.

Hohenwarter, M., Jarvis, D., & Lavicza, Z. (2009). Linking geometry, algebra, and mathematics teachers: GeoGebra software and the establishment of the International GeoGebra Institute. *International Journal for Technology in Mathematics Education, 16*(2), 83–86.

Kilpatrick, J., Swafford, J., & Findell, B. (Eds.). (2001). *Adding it up: Helping children learn mathematics*. National Academies Press.

Mayer, R. E. (2014). *The Cambridge handbook of multimedia learning* (2nd ed.). Cambridge University Press.

Mullis, I. V. S., Martin, M. O., Foy, P., Kelly, D. L., & Fishbein, B. (2020). *TIMSS 2019 international results in mathematics and science*. TIMSS & PIRLS International Study Center.

National Council of Teachers of Mathematics. (2023). *Principles to Actions: Ensuring Mathematical Success for All*. NCTM.

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematical success for all*. National Council of Teachers of Mathematics.

National Research Council. (2001). *Adding it up: Helping children learn mathematics*. National Academies Press.

Ng, O. L., & Rosli, R. (2023). The effectiveness of GeoGebra in geometry learning: A systematic review of empirical studies. *International Journal of Mathematical Education in Science and Technology, 54*(6), 1325–1348. https://doi.org/10.1080/0020739X.2022.2085129

Organisation for Economic Co-operation and Development. (2023). *PISA 2022 Results (Volume I): The State of Learning and Equity in Education*. OECD Publishing.

Piaget, J. (1972). *The psychology of the child*. Basic Books.

Polya, G. (1957). *How to solve it* (2nd ed.). Princeton University Press.

Salsanabila, N., Nurlaelah, E., & Juandi, D. (2024). GeoGebra as a twenty-first-century mathematics learning tool: A systematic literature review. *AIP Conference Proceedings*. **Please verify the publication details before submission.**

Seftiana, R., Wahyudin, & Herman, T. (2024). GeoGebra in mathematics education: A systematic literature review. *Journal of Physics: Conference Series*. **Please verify the volume, issue, page numbers, and DOI before publication.**

Skemp, R. R. (1976). Relational understanding and instrumental understanding. *Mathematics Teaching, 77*, 20–26.

Stylianides, A. J., & Stylianides, G. J. (2007). Learning mathematics with understanding: A critical consideration of the learning principle in the *Principles and Standards for School Mathematics*. *The Mathematics Enthusiast, 4*(1), 103–114.

Suwantarathip, O., & Wichadee, S. (2014). The effects of collaborative learning supported by GeoGebra on mathematics achievement and attitudes toward mathematics. *The Turkish Online Journal of Educational Technology, 13*(2), 148–156.

Tabach, M., & Friedlander, A. (2013). School mathematics and technology. In M. A. Clements et al. (Eds.), *Third international handbook of mathematics education* (pp. 899–932). Springer.

Tall, D. (2013). *How humans learn to think mathematically: Exploring the three worlds of mathematics*. Cambridge University Press.

UNESCO. (2023). *Global Education Monitoring Report 2023: Technology in Education—A Tool on Whose Terms?* UNESCO Publishing.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Zahra, N., & Sudihartinih, E. (2024). Discovery learning assisted by GeoGebra to improve students' mathematical conceptual understanding: A systematic literature review. *Journal of Physics: Conference Series*. **Please verify the volume, article number, and DOI before publication.**

Zengin, Y., Furkan, H., & Kutluca, T. (2012). The effect of dynamic mathematics software GeoGebra on student achievement in teaching trigonometry. *Procedia - Social and Behavioral Sciences, 31*, 183–187. https://doi.org/10.1016/j.sbspro.2011.12.038