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Research Article

Enhancing Students' Conceptual Understanding and Problem-Solving Skills in Learning Trigonometry Through Contextual-Based Mathematical Modeling Instruction

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Abstract

Trigonometry is a crucial topic in high school mathematics that significantly influences students' understanding and problem-solving skills. However, many students face challenges in this area after traditional instructional approaches. By employing a context-based mathematical modeling instructional approach, educators can make trigonometry lessons more meaningful and relevant to students' lives, effectively connecting the academic content to their real-world experiences and contexts. This study aimed to investigate the impact of context-based mathematical modeling instructional approach on secondary school students' conceptual understanding and problem-solving skills in trigonometry. A quasi-experimental non-equivalent pretest, posttest control group design involving 97 Grade 10 students from two separate schools in Bahir Dar City, Ethiopia was employed. The students' conceptual understanding and problem-solving skills were assessed before and after the intervention using a trigonometric concept test and problem-solving tasks developed by the researchers and field experts. The collected data were analyzed using independent, paired sample t-tests and analysis of covariance (ANCOVA). The findings indicated that the treatment group, which participated in the context-based mathematical modeling instructional approach, showed significant improvements in understanding and solving real-life trigonometric concepts and problems compared to the control group. This contextualized approach, supported by effective teacher training and the strategic use of readily available materials significantly enhanced students' conceptual understanding of trigonometry, problem-solving skills, and their ability to apply these concepts to real-world situations. These results suggest that accessible resources, combined with effective instructional delivery, are essential factors in improving mathematics learning outcomes.

Keywords

Instructional Approach, Conceptual Understanding, Problem-Solving, Trigonometry

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1. Introduction

Mathematics must be emphasized in education as a dynamic tool for understanding everyday life, preparing for careers, fostering informed citizenship, enhancing critical problem-solving abilities, and aiding comprehension of other subjects [1]. Researchers assert that mathematics is essential, deeply embedded in culture and society, and provide insights into current and future real-world situations [36]. A crucial question for mathematics educators is how to effectively equip all students to utilize mathematics in daily life and beyond. A process to investigate how students apply mathematics to real-world contexts, known as mathematical modeling [36]. Overall, integrating mathematics into education enhances students' understanding of the world and prepares them for future success.

In particular, trigonometry is a vital topic in secondary school mathematics, playing a significant role in developing students' conceptual understanding, problem-solving, and creative thinking skills [31]. It is also essential for building the foundational knowledge required for calculus and for students pursuing science, technology, engineering, and mathematics (STEM) courses. By fostering these connections and skills, trigonometry lays the groundwork for success in more advanced mathematical concepts and real-life applications. The concepts of trigonometry make people’s lives easier, either in the form of carpentering or construction works or finding the height and distance without measuring the actual height [14].

However, trigonometry is often perceived as a challenging area in mathematics for many students, primarily due to its abstract and complex nature [7, 31]. This complexity can lead to significant difficulties as learners engage with trigonometric concepts and problems [34]. The abundance of formulas in trigonometry can be overwhelming, making it challenging for students to apply these formulas effectively in problem-solving. Consequently, most students struggle to grasp the underlying concepts and abstract elements of the subject [14]. Additionally, the practice of teaching trigonometry contrasts sharply with its real-world applications [24]. Teachers may focus on fulfilling curriculum requirements rather than fostering a deep understanding of the material, while students often learn merely to achieve high grades on examinations [13]. As a result, students may feel less motivated to engage with trigonometry, hindering their ability to demonstrate conceptual understanding.

Overall, national learning assessment results indicate consistently low performance among Ethiopian students in mathematics and science subjects [18].). This situation highlights a significant concern within the Ethiopian education system regarding students' grasp of fundamental mathematical and scientific concepts. Although the Ethiopian government implemented the Strengthening Mathematics and Science Education in Ethiopia (SMASEE) program to enhance education in these areas, student performance continues to fall short of expectations [41]. This suggests that the program, despite its efforts, has not yet achieved its intended impact. Further research is needed to identify the specific challenges hindering student success and to develop more effective strategies for improving mathematics education in Ethiopia.

Students struggle with mathematical problem-solving, especially in trigonometry, due to difficulties in: (1) comprehending mathematical language; (2) grasping concepts; (3) identifying necessary information; (4) formulating solution strategies; (5) lacking experience and skills; (6) understanding the problem's objective; (7) guessing without reasoning; (8) making calculation or writing errors; and (9) lacking motivation. These challenges affect both high school students and prospective teachers [35].

Several studies have examined problem-solving in trigonometry. One notable study involving 80 senior secondary students in Nigeria utilized the Mathematics Achievement Test (MAT) and the Trigonometry Diagnostic Test (TDT) to identify the types of errors made by students. The findings revealed that students still struggle with solving trigonometric [44]. The researchers recommended that teachers provide more opportunities for regular practice and focus on solving problems step by step. Both students and teachers struggle with understanding trigonometric concept and solving trigonometry identities [2]. This can hinder teachers’ ability to effectively explain and guide students through the material. As highlighted by [23], many students struggle to understand and apply mathematical concepts in real-world contexts.

Traditionally, school mathematics has often focused on repetitive exercises and procedural knowledge, emphasizing the rote application of formulas or algorithms [7]. However, approaches that center solely on procedural knowledge, without sufficient attention to understanding mathematical concepts, can hinder and aggravate students' problem-solving abilities [4, 17]. Conventional learning strategies may not optimally foster students' conceptual understanding and problem-solving skills in mathematics [23]. This situation underscores the need for an increased emphasis on conceptual understanding and problem-solving in mathematics instruction, starting from early grades and continuing through high school.

According to the National Center for Education Statistic [32], conceptual understanding in mathematics involves the ability to recognize, label, and generate examples of concepts; utilize various models, diagrams, and manipulative representations; identify and apply principles; understand facts and definitions; compare and contrast related concepts; and interpret the signs, symbols, and terminology associated with these concepts.

A widely accepted definition of a mathematical problem is one where the procedure for solving the task is unknown to the solver, the number of solutions is uncertain, and the task requires critical thinking [40]. This definition underscores the significance of fostering problem-solving abilities in students.

Mathematical problem-solving skills are evident when students can recognize and formulate problems, evaluate data consistency, employ strategies and models, modify procedures, apply reasoning in new contexts, and assess the reasonableness of their solutions. Effective problem-solving requires students to integrate their mathematical knowledge, including concepts, procedures, reasoning, and communication skills [32]. Problem-solving is an important skill that one must have. Problem-solving in mathematics helps students to experience on how to solve daily life problems by applying their mathematical knowledge and skill [44].

Teaching and learning mathematics is often regarded as one of the most challenging academic endeavors for both educators and students [4]. This challenge is evident in the gaps that can disrupt the connection between effective teaching strategies and students' ability to comprehend the material. Addressing these challenges require effective mathematics instruction begins with a clear understanding of students' prior knowledge and what they need to learn, supported by a system that challenges and aids them in mastering the content [28].

Instructional strategies that integrate understanding of the underlying trigonometric concept and proficiency in algebraic manipulation should require [26]. Effective mathematics instruction provides students with several advantages, including the development of their teaching students to retain mathematical concepts as well as to understand the reasons behind and processes involved in their development, critical thinking, reasoning, and problem-solving skills [3].

To help students overcome difficulties in learning trigonometry, research also suggests several effective teaching strategies: Initiating angle measurement and utilizing visual aids can provide more concrete understandings of trigonometric concept [30]. Presenting multiple representations, such as graphs, tables, and algebraic forms, can support students in making connections between different perspectives on trigonometric functions [16]. In order to build conceptual understanding and procedural fluency, students must have learning experience that provides them with connected mathematical ideas [26]. Model-facilitated learning (MFL) is one of learning approaches which supports students to explore and elaborate the relationship between one concept and the other [26]. MFL provides the opportunity for students to understand concepts through exploring activity under computer-based model. Further, in MFL students build their own rules and formula based on their conceptual understanding which will be used for solving problems. Contextual learning strategy had a significant effect on improving conceptual understanding and mathematical problem-solving abilities [23].

Students must learn mathematics with understanding, actively building new knowledge from their experiences and prior knowledge (National Council of Teachers of Mathematics [33]. This approach to mathematics learning aligns with constructivist principles, where students actively construct their own understanding by connecting new information to their existing knowledge and experiences [33]. By engaging in this active, meaningful learning process, students are better able to develop a deeper, more robust understanding of mathematical concepts, rather than relying on rote memorization or procedural knowledge alone.

By fostering conceptual understanding and problem-solving skills, teachers can equip students with the tools they need to navigate real-world mathematical challenges and become confident, independent thinkers in the field of mathematics [29]. Conceptual understanding aids students in avoiding errors and misconceptions when solving problems. This understanding enables students to develop skills in performing calculations accurately and efficiently, with knowledge of when and how to apply them appropriately [33].

Recent research continues to emphasize the significance of problem-solving skills, particularly in the context of trigonometry. A study conducted by Chen focused on the relationship between problem-solving abilities in trigonometry and academic achievement among high school students [9]. The findings revealed a strong positive correlation between proficient problem-solving skills in trigonometry and higher academic performance in related subjects. The study highlighted the importance of developing problem-solving skills in trigonometry to enhance mathematical understanding and achievement.

Therefore, Contextual Mathematical Modeling Instruction (CMMI) emphasizes the application of mathematical knowledge and skills in real-world contexts, enabling students to connect mathematics to their everyday lives [23]. Contextualized Teaching and Learning (CTL) is an instructional approach aimed at enhancing relevance and engagement by linking foundational skills and academic or occupational content to concrete, real-world applications. This method focuses on contexts that are meaningful to students [6]. CTL prioritizes hands-on, experiential learning over abstract or purely theoretical instruction, recognizing that many students learn more effectively when content is presented in a tangible, contextual manner [6].

The modeling process in mathematical modeling instruction involves defining and identifying the characteristics of real-world problems, representing these problems with mathematical symbols, and analyzing and interpreting the resulting models [6].

MMI aligns with constructivist principles, as it encourages students to actively construct their understanding of mathematics through hands-on activities, creating models, and deepening their conceptual understanding [8, 15]. Allowing students to create their own models rather than relying solely on existing ones is considered beneficial in this instructional approach [15]. In its standards for school mathematics, the [33] argued that the purposes of using mathematical modeling are to deepen the relationships among different topics of mathematics (e.g., numbers, algebra, and geometry) and to solve problems faced by learners due to the impact of such a process on the understanding of mathematics.

Mathematical modeling is a bridge through which the teacher can facilitate students' learning of mathematics [15]. Modeling represents mathematical concepts and presents them in drawing or in picture, linking them to the reality of learners and their daily lives. Modeling also contributes to the development of understanding and thinking [8]. [21] Agreed with this perspective in presenting mathematical modeling as a process of developing a model based on real-life problems and using the model to solve the identified problems.

Overall, modeling and MM serves as a bridge between theory and practice, making mathematics more accessible and relevant to students. In mathematical modeling, language also plays a very important role because it is a resource that supports mathematical symbolism, notations, and images in the process of building mathematical meanings and ideas [38].

CMMI approach considers REACT strategy: (REACT) to mean Relating, Experiencing, Applying, Cooperating, and Transferring in the process of teaching and learning mathematics [11]. Where: - Relating: Linking the concept to be learned with something that students already know. E-Experiencing: Hands on activities and teacher explanation allow students to discover new knowledge. A-Applying: Students apply their knowledge to real-world situations. C-Cooperating: Students solve problems as a team to reinforce knowledge and develop collaborative skills. T-Transferring: Students take what they have learned and apply it to new situations and contexts. The other strategy is [22] 3C3R Model which has a Core component includes (3C) means; content, context, and connection; while processing components consist of (3R) means researching, reasoning, and reflecting.

Solving math problems including trigonometry needs problem solving framework developed by [37], who is widely recognized as a pioneer in mathematical problem solving in mathematics education. Polya's approach involves four key stages, such as;- understanding the problem, devising a plan, carrying out the plan and looking back which will be explained in detail below. The students must follow those steps so they can handle the trigonometry problems. It is very important to understand, how the students solve their trigonometry problems, so the teacher can give some suggestions.

For the reasons stated above, the approach to learning mathematics, particularly trigonometry, needs to be updated to enhance students' problem-solving skills and advance their conceptual understanding. In other words, there is a need to apply a contextual mathematical modeling instructional approach and assess its impact on learners' comprehension of trigonometric concepts and problem-solving abilities. Accordingly, the current study aims to evaluate the effect of the contextual- based mathematical modeling instructional approach on the understanding of trigonometric concepts and problem-solving skills among students at two secondary high schools in Bahir Dar City. The study tries to answer the following main questions:-

1) Is there a significant difference in students' conceptual understanding of trigonometry between the intervention and control groups?
2) Is there a significant difference in students' problem-solving skills of learning trigonometry between the intervention and control groups?

2. Theoretical Framework

This study is grounded in constructivism and social theory, heavily influenced by Vygotsky's social critical theory. Constructivism views learning as an active and creative process, contrasting with passive reception. A key distinction within this framework is the identity of the knowledge constructor: is it the individual, a group, or a community? Consequently, constructivist theories can be classified into individual and social constructivism. In this context, knowledge is collaboratively built, and the teacher's role shifts from being the sole dispenser of knowledge to a motivator, guide, and resource. Social constructivism emphasizes a learner-centered, learner-directed, and collaborative teaching and learning process, where learning is supported by teacher scaffolding and community interactions [45]. Learning mathematics through a mathematical modeling (MM) instructional approach can thus be understood as both an individual and social process.

Additionally, a participatory perspective is adopted, conceptualizing learning as changes in participation and recognizing knowledge as integral to an individual's engagement in social practices [46]. Contextual learning research suggests that constructivist processes like critical thinking, inquiry learning and problem-solving must be situated within relevant physical, intellectual, and social contexts [2]. This approach recognizes and highlights the natural conditions of knowledge, making learning experiences more relevant and meaningful for students. By fostering relationships both inside and outside the classroom, contextual learning helps students build knowledge that is applicable to lifelong learning [43]. It presents a concept linking the material that students are studying in the context of the material used, and the relationship of how students learn.

The foundation of contextual learning lies in constructivist theory, which suggests that students actively construct their own knowledge. In contrast to viewing knowledge as a fixed set of facts or rules to be memorized, constructivism emphasizes the importance of constructing meaning through real experiences. Understanding this theory is crucial within the context of learning, as it shifts the focus from the transfer of ideas from teacher to student to a more interactive process of knowledge construction [43]. By integrating these theoretical perspectives, this study aims to enhance students' conceptual understanding and problem-solving skills in mathematics, particularly in the context of trigonometry.

3. Materials and Methods

3.1. Research Design and Sampling

This study aimed to examine the impact of CMMIA on students' conceptual understanding and problem-solving skills in learning trigonometry in secondary schools. The researchers used a quantitative research approach with a non-equivalent control-group quasi-experimental pretest, posttest design that included a covariate. This design allowed the researchers to determine the effect of the independent variable (CMMIA) on the dependent variables (conceptual understanding and problem-solving skills) in real-life settings, and to find causal relationships [42, 12]. The study also used pretests as a covariate to account for any initial variances in conceptual understanding and problem-solving skills among the students, which helped to strengthen the internal validity of the study [42]. The design of the study, is simply shown as follows.

Table 1. *Quasi-Experimental Pre-test, Post-test Control Group Design.*

Groups	pre-test scores	Intervention	post-test scores
Experimental group	O_1	X	O_2
Control group	O_3		O_4

X: represents treatment (CMMIA) applied on the experimental group.

The study was conducted in two public secondary schools in Bahirdar City, Ethiopia: Tana Haik and Fasilo. Tana Haik was designated for the experimental group, while Fasilo served for the control group using simple random sampling. Within each school, one intact class of grade 10 students was randomly selected. The study involved a total of 97 students, with 50 students from the experimental group (Tana Haik) and 47 students from the control group (Fasilo).

Service, qualifications, content, teachers' gender, and duration of learning sequences remained consistent between the experimental and control groups. The gender distribution was also almost similar across both groups, as indicated by the chi-square test result, χ^2 (1) = 0.02, p = 0.886. This suggests that the two groups were well-balanced in terms of gender composition, which is an important factor to consider in educational research.

Data was collected using a combination of 10 multiple-choice items and 4 open-ended problem solving tasks. These assessments were designed to evaluate students' understanding of basic trigonometric ratios and their ability to apply this knowledge to solve problems involving angle of elevation, trigonometric identities and angle of depression. The test items were carefully constructed to ensure appropriate difficulty levels, comprehensive coverage of the trigonometry curriculum (specifically trigonometric identities, angle of elevation, and angle of depression), and the elicitation of problem-solving skills, with input from experienced teachers and subject matter experts.

Table 2. *Gender Group Cross tabulation.*

	Groups		
Gender	**Control**	**Experimental**	**Total**
Female	27	28	55
Male	20	22	42
Total	47	50	97

Prior to administering the conceptual test and problem-solving tasks to the main sample groups as a pre-test, the researchers conducted a pilot study and data was collected from a separate group of 50 grade 11 students at Ghion Secondary School in order to assess the reliability of the instruments. The internal reliability of the multiple-choice conceptual test was calculated using [25] method and found to be 0.76, which is considered a very reasonable value. Additionally, the inter-rater reliability of the aggregate rubric data for the problem-solving tasks was assessed using the Intra-class Correlation Coefficient (ICC) test. This analysis showed good agreement between the two raters, with a kappa coefficient (κ) of 0.79.

Before the intervention, both sampled groups of the study completed a pre-test consisting of the conceptual understanding items and the trigonometry problem-solving tasks. After the five-week treatment period a post-test was administered to measure the final scores and the variation in performance between the experimental and control groups.

3.2. Intervention of the Study

After the pre-tests have been completed, the experimental group's teacher was trained on how to effectively implement the CMMI approach for the specific topics trigonometry such as ratios, reduction formulae, trigonometric identities, sine and cosine rules, trigonometric equations, angles, and applications of trigonometry.

This facilitate that the teacher implemented the intervention based on the prescribed procedure. Service, qualifications, content, teachers' gender, and duration of learning sequences were consistent between the experimental and control groups.

The key activities for the experimental group involved implementing the CMMI approach were:-The REACT (Relating, Experiencing, Applying, Cooperating, and Transferring) strategy in mathematics teaching and learning.

The REACT strategy comprises:

1) Relating: Connecting the concept to be learned with students' prior knowledge.
2) Experiencing: Hands-on activities and teacher explanations enable students to discover new knowledge.
3) Applying: Students use their knowledge to solve real-world problems.
4) Cooperating: Students collaborate to solve problems, reinforcing their knowledge and developing teamwork skills.
5) Transferring: Students apply what they have learned to new situations and contexts.

The 3C3R model is also utilized in this strategy, which has a Core component consisting of three elements: content, context, and connection. The 3R processing components include researching, reasoning, and reflecting. This model ensures that students understand the content in context, connect it to their prior knowledge, and process it through researching, reasoning, and reflecting.

The study integrated George Polya's problem-solving framework into the assessment of students' trigonometry problem-solving skills. Polya's approach consists of four stages:

1) Understanding the problem: Defining known information, clarifying what is being asked, ensuring sufficient data, and restating the problem in operational terms.
2) Devising a plan: Identifying similar problems, recognizing patterns or rules, and creating a plan to connect given information to the desired goal.
3) Carrying out the plan: Implementing planned procedures and checking work along the way.
4) Looking back: Analysing and evaluating procedures and results, considering alternative approaches, and identifying potential generalizations or applications.

To assess grade 10 students' solutions to four individually assigned trigonometry problems, the researchers incorporated Polya's four-stage problem-solving framework into the scoring rubric for the intervention group. Each of the four problem-solving skills test items was scored out of 10 points, resulting in a total possible score of 40 points. In contrast, the control group learned trigonometry using traditional instructional approaches which are generally teacher-directed, and follow ‘cookbook’ steps of activities.

Table 3. *The Scoring Rubric of Mathematics Problem Solving Ability adapted from Polya -Strategy. delted here.*

Score	Understanding the problem	Constructing or devising plan	Carrying out the Plan	Checking or looking back the result
0	Misinterpretation or incorrect at all	No plan, irrelevance of constructing plan	Not performing calculation’s at all	Not checking back at all
1	Misinterpretation partially, disregard of problem condition	Constructing a plan, but it cannot workable	Performing the right procedure and probably produce a correct answer but miscalculate	Checking back but incomplete
2	Understanding the problem clearly and contextually i.e. (formulate: what is known, what is asked, whether the information sufficient, condition what should met, restate the original problem in a more solvable	Constructing the right plan but incorrect in the result or no result	Performing the right procedure and getting a correct answer	Analyzing, and evaluating whether the procedures applied and the results obtained are correct, whether there are other procedures that are more effective, whether procedures have created can be used to solve similar problems
3		Constructing the right plan but incomplete		
4		the solver uses his/her knowledge to plan how to connect the given data to the desired goal		
	Maximum score is 2	Maximum score is 4	Maximum score is 2	Maximum score is 2

3.3. Data Analysis

The study was addressed two main research questions which were stated above. Therefore, these two research questions investigated the effect of a contextual mathematical modeling-based instructional approach by comparing the performance of the treatment and control groups on a trigonometry conceptual test and four trigonometry problem-solving tasks. To examine the progress of each group from pretest to posttest, the researchers were used independent and paired sample t-tests. Besides, we conducted analysis of covariance (ANCOVA) using the pretest scores as a covariate to compare the differences between the posttests of the experimental and control groups.

4. Results

The researchers thoroughly assessed the normality of the data to ensure the validity of their statistical analysis. Visual techniques were employed using SPSS, including histograms, normal Q-Q plots, and boxplots, which demonstrated that the test results were approximately normally distributed. Additionally, statistical tests for skew-ness and kurtosis were conducted, and the values were found to be within the acceptable range of -2 to +2, further confirming the normal univariate distribution of the data [19].

Moreover, the researchers tested and satisfied the assumption of homogeneity of variance using Levene's F-test [27], as described in Table 4 of the study. This comprehensive approach to evaluating the underlying assumptions of the data strengthens the reliability and validity of the statistical inferences drawn from the study.

Table 4. *Skew-ness, Kurtosis and Levene's Test for Equality of Variance.*

Dependent variable	Skew-ness		Kurtosis		Levene's Test for Equality of Variances	
	pretest	Post-test	Pre-test	Post-test	Pre-test	Post-test
CUT	0.63	0.44	1.06	0.44	F = 1.9, p = 0.17	F= 3.19, p= 0.08
PSST	- 0.8	0.66	0.72	0.07	F= 1.98, p = 0.16	F= 0.24, p= 0.62

CUT - Conceptual Understanding Test
PSST - Problem - Solving Skill Test

Building upon the systematic examination of the data's normality and homogeneity of variance, the researchers proceeded to answer the first research question. The researchers employed a paired-sample t-test and calculated effect sizes using Cohen's d to compare the pre-test and post-test scores on the conceptual trigonometry test within the group. The results of this analysis are presented in Table 5 below. This analytical approach allowed the researchers to determine the magnitude and statistical significance of the changes in students' conceptual understanding of trigonometry from the pre-test to the post-test. The use of effect sizes, in addition to statistical significance testing, provides a more comprehensive understanding of the practical relevance and educational implications of the findings. The analysis revealed that both groups had relatively low pre-test mean scores, indicating limited prior knowledge of the selected trigonometry content. However, the experimental group achieved significantly higher post-test scores compared to the control group, despite their similar pre-test performance. Paired-sample t-test confirmed that both groups showed significant improvements from pre-test to post-test ($p < 0.05$). Notably, the experimental group demonstrated a large effect size ($d = 1.02$), whereas the control group exhibited a small effect size ($d = 0.35$). These findings align with conventional thresholds for interpreting effect sizes, where small, medium, and large effects are defined as ($0.2 \le d < 0.5$), ($0.5 \le d < 0.8$), and ($d \ge 0.8$), respectively [10]. This indicates that the instructional approach used in the experimental group was substantially more effective in enhancing students' conceptual understanding of trigonometry.

Table 5. *Results of the paired-sample t tests for the Trigonometry Conceptual Test.*

	Pre-test			post-test				Effect size
Group	N	M	SD	M	SD	t	p	Cohen's d
Experimental	50	2.86	1.44	4.46	1.67	6.84	< 0.05	1.02

	Pre-test			post-test				Effect size
Control	47	2.79	1.02	3.21	1.27	2.12	< 0.05	0.35

An independent sample t-test revealed no significant mean difference in pre-test scores between the two groups t (95) = 0.29, p = 0.78). However, ANCOVA controlling statistically for pretest scores, showed a significant difference in post-test scores, $F (1, 93) = 16.19$, $p = 0.001$, $\eta^2 = 0.148$, indicating that the treatment group outperformed the control group in their conceptual understanding of trigonometry. The partial η^2 value suggests that the intervention accounted for 14.8% of the variance in post-test scores, highlighting the effectiveness of the Contextual Mathematical Modeling Instructional approach in enhancing students' conceptual understanding of trigonometry compared to traditional methods.

Table 6. *ANCOVA for trigonometry conceptual understanding as a Function of the two Groups, Pre-tests as a Covariate.*

Type of Questions	Source	df	Mean square	F	p	Eta^2
conceptual understanding in trigonometry	Pre-test C	1	17.001	9.481	.003	0.093
	Pre-test P	1	11.451	6.386	.013	0.064
	Groups	1	29.027	16.188	.001	0.148
	Errors	93	1.793			

To answer research question 2, the researchers have used the same analysis techniques namely paired sample t test and ANCOVA. Therefore, from the paired sample t test analysis the following results were obtained as shown below in table 7.

The descriptive statistics showed that the experimental group scored higher on the problem-solving performance posttest compared to the control group, despite the groups demonstrating similar pre-test performance. The paired-sample t-test revealed statistically significant improvements ($p < 0.05$) in problem-solving performance from pre- to post-test for both groups. However, the experimental group exhibited a large effect size ($d = 1.91$), indicating substantial improvement, while the control group showed a moderate effect size ($d = 0.68$).

Table 7. *Results of the paired-sample t test for the trigonometry problem solving tasks.*

	Pre-test			post-test				Effect size
Group	N	M	SD	M	SD	t	p	Cohen's d
Experimental	50	10.92	1.47	14.46	3.24	8.96	< 0.05	1.91
Control	47	10.40	1.89	12.83	2.64	7.65	< 0.05	0.68

Further analysis using an independent samples t-test found no statistically significant difference in pretest problem-solving scores between the groups t (95) = 1.5, p = 0.16. However, the one-way ANCOVA, controlling statistically for pretest scores, demonstrated a significant difference in post-test problem-solving performance between the groups, $F (1, 93) = 13.03$, $p = 0.001$, $\eta^2 = 0.123$. This suggests that after accounting for prior problem-solving ability, the experimental group achieved significantly higher posttest problem-solving scores compared to the control group. The partial η^2 value indicates that 12.3% of the variance in problem-solving performance was explained by the Contextual Mathematical Modeling Instructional intervention.

These findings provide strong evidence that the Contextual Mathematical Modeling Instructional approach was more effective than the traditional instructional approach in improving students' problem-solving skills.

Table 8. *ANCOVA for trigonometry problem-solving performance as a Function of the two Groups, Pre-tests as a Covariate.*

Type of Questions	Source	df	Mean square	F	p	Eta^2
Problem solving skills in trigonometry	Pretest C	1	20.208	3.323	.072	0.035
	Pretest P	1	86.697	14.258	.000	0.133
	Groups	1	79.223	13.029	0.001	0.123
	Errors	93	6.080			

5. Discussion

The findings of this study indicate that the teaching approaches used for both the experimental and control groups were effective in improving students' understanding of trigonometric concept. Paired sample t-tests revealed statistically significant differences ($p < 0.05$) between the pre-test and post-test scores for both groups. This suggests that the instructional methods employed in both groups successfully enhanced students' conceptual understanding of trigonometric concepts.

However, the effect sizes between the two groups were remarkably different. The experimental group displayed a large effect size (Cohen's d = 1.02), while the comparison group had a smaller effect size (Cohen's d = 0.35). This difference implies that the learning approach implemented in the experimental group, which used the different strategies in CMMIA had a stronger impact on improving students' conceptual understanding compared to the approach used in the control group.

Importantly, independent sample t-test showed that the pretest score between the groups has no significant difference however, the one-way ANCOVA analysis, which controlled for the pretest scores, found significant difference between the two groups in their posttest score, $F(1, 93) = 16.19$, $p = 0.001$, $\eta^2 = 0.148$. This result indicates that the CMMI approach is recommended than the traditional approach to enhance students' conceptual understanding in trigonometry leaning. These findings align with several research findings on the benefits of CMMI. The studies indicate that contextual learning strategies significantly enhance students' conceptual understanding in trigonometry [23]. Furthermore, as part of the CMMI, research emphasizes that effective mathematics instruction should actively engage students in problem-solving, reasoning, and the construction of mathematical knowledge [40]. This approach not only fosters a deeper understanding of mathematical concepts but also equips students with essential skills for applying mathematics in real-world situations.

Regarding the problem-solving performance test, Paired sample t-tests revealed statistically significant differences ($p < 0.05$) between the pre-test and post-test scores for both groups. This suggests that the instructional methods employed in both groups successfully enhanced students' trigonometric problem solving skills. However, the experimental group exhibited a large effect size (d = 1.91), indicating substantial improvement in students' problem solving performance, while the control group showed a moderate effect size (d = 0.68). The results were more favorable for the experimental group.

Additionally, the one-way ANCOVA analysis revealed a significant difference between the two groups, $F(1, 93) = 13.03$, $p = 0.001$, $\eta^2 = 0.123$ in their problem solving performance. This finding indicates that the Contextual Mathematical Modeling instructional practice is notably important for the improvement of student`s problem solving abilities compared to the traditional instructional approach in learning trigonometry. This result aligns with previous research findings that reveal the CMMI approach significantly enhances students' trigonometric problem-solving performance [40]. Effective mathematics instruction also fosters students' problem-solving abilities [3].

6. Conclusion and Recommendations

The findings of the study demonstrate that the contextual mathematical modeling instructional approach was effectively improved students' understanding of trigonometric concepts and problem solving skills with larger effect size, indicating a stronger impact on conceptual understanding and problem solving skills compared to the traditional method. These outcomes highlight the effectiveness of contextual learning strategies in enhancing students' conceptual understanding and problem-solving skills in trigonometry, consistent with existing research on the benefits of contextualized mathematical modeling instruction (CMMI). Thus, it is recommended that teachers utilize available materials and information from their surroundings, supported by effective training and well-delivered lessons. Future studies should aim to conduct parallel research across a broader scope, incorporating other disciplines to improve generalizability. Additionally, it is advisable for future research to utilize a mixed-methods design to assess how the intervention helps students' understand trigonometric concepts and problem solving skills.

Abbreviations

MAT	Mathematics Achievement Test
TDT	Trigonometry Diagnostic Test
MFL	Model-facilitated Learning
CTL	Contextualized Teaching & Learning
CMMI	Contextual Mathematical Modeling Instruction
REACT	Relating Experiencing Applying Cooperating & Transferring
ICC	Intra-class Correlation Coefficient
CUT	Conceptual Understanding Test
PSST	Problem Solving Skill Test

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Ethical Consideration

Ethical approval for this study was obtained from Hawassa University College of Education Research Ethics Review Committee (COE-REC/018). All participants provided written consent for their participation and the use of their anonymous data. Prior to data collection, the research objectives, potential impacts, and possible outcomes were communicated to school principals and teachers, who consented to participate. Students were informed that participation was voluntary and that they could withdraw or decline to answer questions at any time. No participants withdrew, and no issues arose during the study.

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Data Availability Statement

Data will be made available upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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