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Development and Implementation of Geogebra-based Interactive Learning Module as Teaching Tools in Trigonometry

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Abstract: Students' low performance in trigonometric function transformation, is attributed to a lack of conceptual understanding and misconceptions. This calls for innovative and interactive learning materials that may facilitate students' visualization and conceptual understanding of trigonometric concepts. This study aimed to develop and implement a Geogebra-based ILM intended for enhancing students' understanding of trigonometric function transformation. This study utilized a developmental and experimental research design. The validation of the developed Geogebra-based ILM was done by peers and expert evaluators, while its effectiveness was determined by comparing the students' pretest and posttest results. Results showed the importance of incorporating interactive and visual instructional tools in teaching, as identified by the mathematics teachers through the Interactive Learning Module. The Geogebra-based ILM was designed using a backward design aligned with the learners' needs. The developed Geogebra-based ILM showed high agreement between peer and expert validators, proving that it is valid, appropriate for learners, and suitable for implementation. The study showed a significant improvement in the posttest scores of the students after the implementation of the Geogebra-based ILM, and the learners mastered concepts that were difficult for them before. The results of the paired sample t-test proved that the Geogebra-based ILM was effective in enhancing students' conceptual understanding by correcting misconceptions through interactive, visual, and dynamic learning. The study concludes that the Geogebra-based ILM is effective in enhancing students' performance and conceptual understanding of trigonometric concepts. It is therefore recommended that educators make use of technology-based modules, especially Geogebra to enhance active learning.

Keywords: *Geogebra-Based Interactive Learning Module (ILM), Trigonometry, Instructional Needs, Development, Implementation.*

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I. INTRODUCTION

Filipino students were left behind compared to other participating countries in 2022 PISA. According to OECD, PISA (2022), only a small number of Filipino students achieved high scores in mathematics. Majority of students consider trigonometry a tough subject because they struggle to understand trigonometric concepts and visual representations resulting in low performance (Tyata, 2021). Trigonometry is a branch of mathematics focused on properties of triangles and trigonometric functions and their applications.

In the dynamic landscape of contemporary education, the integration of technology to instruction and learning materials has become an indispensable facet of effective teaching and learning. The integration of technology supports educators by addressing the limitations of traditional teaching methods through the incorporation of technology-based tools and facilities in the teaching and learning process (Hero, 2019). Traditional teaching methods often rely on fixed representations and rule-based approaches, which may limit learners' active participation and conceptual understanding.

According to Azucena et al. (2022), GeoGebra software intends to assist educators in varying teaching methods to improve students' understanding and confidence in mathematical concepts through effective teaching and learning. The integration of Geogebra in the learning module has several benefits, including more efficient and effective teaching, improved student achievement, and the ability to create simulations and visualizations that help students to understand real-world applications of mathematical concepts. As technology continues to advance, it is likely that the integration of Geogebra in math education will continue to grow and evolve, leading to improved student outcomes and a deeper understanding about the subject matter.

To address the underlying problems concerning teaching and learning of trigonometry is through the development of Geogebra-based interactive learning modules. Geogebra-based ILM may enhance conceptual understanding of the students where Geogebra allows visual representations of the trigonometric functions. By interacting with visual representations in each function, students can better understand the properties, relationships, and differences that they struggle with through fixed or static methods alone. According to Baye et al. (2021), integrating Geogebra in the teaching process improved the students' conceptual understanding and significantly better than the static method. Additionally, ILM can promote active learning of the students by encouraging them to explore, hypothesize and test their ideas by manipulating each function. Students can build their knowledge through experience and interaction rather than passive absorption. Furthermore, exposing students to technology prepares them for their academic and professional futures. Incorporating this Geogebra-based ILM into their learning experience equips them with skills needed when they are in the field of teaching. Lastly, this Geogebra-based ILM can facilitate teacher innovation and instructional efficiency. Teachers can create dynamic learning demonstrations, simulations, and activities that help explain complex ideas more clearly and make the learning easier.

Despite the strides made in learning modules into trigonometry education, specific gaps persist in understanding the students' performance and engagement. The existing modules are static and do not fully support active, independen learning. The development of technology-based interactive modules aims to bridge these gaps by enhancing concept understanding, promoting active learning, preparing students for technological fluency, and facilitating teacher innovation and instructional efficiency will support the diverse learners in a blended learning. According to Bright et al. (2024), they are recommending that technology in mathematics should be included in the teaching-learning process to enhance the students' performance in mathematics. It is also recommended that math software like Geogebra be used in the teaching learning process.

This study aims to develop and implement the Geogebra-based interactive learning module as teaching tools in trigonometry. Specifically, this study seeks to answer the following questions: what are the instructional needs of the students in Trigonometry?, how should the GeoGebra-based interactive learning module be designed and developed?, how the peer and expert validator evaluate the GeoGebra-based Interactive Learning module?, is there a significant difference in the evaluation of the developed Geogebra-based Interactive Learning Module between the peer and expert validators?, and what is the pretest and posttest performance of the students before and after using the developed Geogebra-based interactive learning module and its differences?

II. MATERIALS AND METHODS

➢ *Participants*

The researcher used total enumeration in the study. According to Singh (2022), total enumeration is one approach of using the entire population with a small number of samples. This approach eliminates sampling errors and provides data on all the respondents. In this study, a total of 25 first year Bachelor of Secondary Education Major in Mathematics in Western Philippines University Puerto Princesa Campus are the respondents. These respondents were selected based on their consent to participate in the research study. Additionally, 20 mathematics teachers evaluated the instructional needs based on the identified difficulties of the students in Trigonometry. Mathematics teachers were chosen as the respondents since they had direct classroom experience, were knowledgeable about pedagogy, and were aware of the problems encountered by the learners in learning mathematics For the validity of the designed and developed Geogebra-based ILM, 21 validators from the various disciplines in education and from the committee members at the college and university level were selected.The criteria for selecting the experts were that they have a background in the development of instructional materials, are currently appointed as one of the instructional material committee in college and university level and have a minimum of three years of teaching experience. Meanwhile, the criteria for selecting peer reviewers were their teaching experience and knowledge about classroom teaching, thus allowing them to determine the practicality and usefulness of the module. The task of these evaluators was to determine the validity of the developed ILM before implementation.

➢ *Methods*

The study employed developmental design using the ADDIE model to develop an interactive learning module, a comparative and one-group pretest-posttest experimental design to determine the feasibility of the learning module that is being developed. According to Richey and Klein (2005), developmental research could be of two distinct types depending on the structure of the study. Developing and implementing interactive learning modules will fall into the Type I category. Type I focused on a specific product and in this study, an interactive learning module is being developed and investigated. The interactive learning module was designed as a solution to the particular problem. Comparative design focuses on the difference between the peer and expert evaluations on the developed ILM, while one group pretest posttest experimental design focuses on evaluating the effectiveness of interactive learning modules. Using the developed module, the researcher aims to enhance students' performance in Trigonometry.

➢ *Instruments*

To identify the instructional needs and what specific topics or questions students demonstrated low performance, analyzing the performance of the students in the previous year was analyzed using item analysis. To evaluate the validity of the ILM to be developed and implemented in this study, criteria from the Western Philippine University Instructional

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Material Evaluation were adapted to ensure the relevance of the module to the University standards. The three major themes of the evaluation instrument were content, usability, and technical accuracy. These themes served as the primary domains of the instruments, which were qualitatively measured to establish the validity of the ILM. The content was analyzed for the degree to which it was correct, relevant, and consistent with the educational goals. The usability was concerned with navigability, user friendliness, and accessibility to the learners. The technical accuracy component evaluated the mathematical and conceptual accuracy and functionality of the interactive features. The expert and peer rated the ILM using a 4-point Likert scale. Lastly, a 30-item researcher-made test questionnaire with a total of 30 points, reviewed and validated by three Mathematics Professors, was used to determine the pretest and posttest performance of the students during the implementation stage to gauge how the students learned through the interactive learning module.

- *Data Analysis*

The students' least mastered skills in Trigonometry and instructional needs were analyzed using frequency, difficulty index and percentage. Additionally, to describe the validity of the developed module, the mean scores and standard deviation of each criterion as evaluated by peer and expert validators were analyzed. To describe the performance of the learners before and after the use of Geogebra-based Interactive learning modules weighted mean of the pretest and posttest scores was utilized to describe the mean scores of each test, while standard deviation was used to describe the variability of the scores. Moreover, to determine the differences in the evaluations of the peer and expert validators of the developed Interactive Learning Module, the Mann-Whitney U test was utilized since the data violates the assumptions for normality and to determine the effectiveness of the developed module, since the data does not violate the assumptions for utilizing the parametric test, paired sample t-test was utilized to determine the difference between the pretest and posttest scores of the students.

III. RESULTS AND DISCUSSION

The researchers was able to address the instructional needs of the students in their Trigonometry subject using Geogebra-based Interactive learning module. The validation of the developed module and the pretest and posttest comparison was made. The researcher was able to show how the Geogebra-based ILM had a significant effect on the conceptual understanding of the students in Trigonometry.

- *Instructional Needs of the students in Trigonometry*

The results shown in Table 1 were part of Phase 1 of the Analysis Phase. A data-driven approach is used in this phase to examine students' performance in graphing trigonometric functions.

Table 1. Students' Least Mastered Skills in Trigonometry

Question	*f*	Difficulty Index	Descriptive Level
1. What is the range of the function $y = 2 + sinx$?	5	.20	Least Mastered
2. A cosine function is given by $y = 2cos(x - \frac{\pi}{3} + 1)$. Which of the following sets of ordered pairs correctly represents key points of this function over one period from 0 to 2π?	9	.36	Low Mastery
3. Consider the function $y = -cot(2x + \frac{\pi}{4})$. Which transformation is applied to the parent function $y = cotx$?	8	.32	Low Mastery
4. Which of the following is the correct transformation of the tangent function of $y = 2tan\,(x)\ + 1$.	8	.32	Low Mastery
5. The function $y = cot\ \left(\frac{1}{2}x - \frac{\pi}{6}\right)$ represents which type of transformation of $y = cotx$?	7	.28	Low Mastery
6. What transformation occurs when the graph of $y = csc\ (x)$ becomes $y = csc\ \left(x - \frac{\pi}{3}\right) + 2$?.	8	.32	Low Mastery
7. The function $y = -3sec\ \left(\frac{1}{2}x + \pi\right) - 1$ represents what sequence of transformations from $y = sec\ x$?	8	.32	Low Mastery

Note: *0 - .20(Least Mastered), .21-.40(Low Mastery), .41-.60(Developing Mastery), .61-.80(Well Mastered), .81-1.0(Highly Mastered)*

Table 1 show that students face challenges in certain key areas, which include the set of transformed trigonometric functions, key points, periodicity, interpretation and classification of transformations, correct order of transformations, and reciprocal trigonometric functions.

Table 2 below identifies the instructional needs in trigonometry as suggested by the mathematics teachers during the Phase 1 of the Analysis stage.

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Table 2. Level of Instructional Needs in Trigonometry

Instructional Needs	*f*	Percentage(%)	Description
Visual Aids (Charts and Graphs)	7	8.33	Low Need
Trigonometric Models	7	8.33	Low Need
Projector/Digital Display	8	9.52	Low Need
Graphing Calculator	5	5.95	Low Need
Interactive Learning Module	15	17.86	High Need
Manipulatives for Unit Circle	3	3.57	No Minimal Need
Guided Activity Sheets	5	5.95	Low Need
Video Lessons/Tutorials	10	11.90	Moderate Need
Step-by-step Problem Guides	11	13.10	Moderate Need
Assessment and Feedback Tools	6	7.14	Low Need
Collaborative learning Materials	3	3.57	No Minimal Need
Workbook	4	4.76	No Minimal Need

Note: *17 – 20(Critical Need),13 - 16(High Need), 9 - 12(Moderate Need),5 - 8(Low Need),0 - 4(No Minimal Need)*

The result shows that among the 20 mathematics teachers, 15 (17.86%) suggested the Interactive learning module, which is described as high need in classroom instruction delivery. In contrast, collaborative learning materials and manipulatives for the unit circle were each suggested by three mathematics teachers (3.57%), which is described as no minimal need.

The response from the mathematics teachers revealed that the Interactive Learning Module (ILM) as an instructional need is consistent with the difficulties outlined in Table 5, such as understanding the transformations of graphs, such as amplitude, phase shift, horizontal shift, and asymptotic behavior. The high proportion of the ILM implies that there is a high need for a learning strategy that will allow the students to learn these concepts in an interactive way.

This finding is supported by Carstens et al. (2021), who state that technology enhances learning opportunities and increases student comfort and engagement. Similarly, Dyhrkopp (2022) reinforces that technology has the potential to greatly change the way things are done in classrooms by means of digital differentiation, one-to-one teaching, and flipping the classroom methods.

This suggests that students benefit from an interactive environment where they can manipulate the variables and see the immediate effects on the graph. In this way, the student is able to make abstract concepts, such as the effects of vertical shifts on the range or the effects of phase shifts on the key points, more concrete. This is in line with the gaps that were identified, as the students were not able to make the correct interpretations, nor were they applying the transformations in the correct order.

- *Design and Development GeoGebra-Based Interactive Learning Module*

The design and development of the ILM were systematically grounded based on the identified difficulties encountered by the students in graphing trigonometric functions in Phase 1.

In response to these identified instructional needs, the ILM was intentionally designed to integrate dynamic and interactive features using Geogebra, therefore, a Design Logic Table was developed. In this table below, the student difficulties identified during the phase 1 are explicitly related to the corresponding feature in the GeoGebra-based ILM. Thus, the design of the ILM is a direct response to the difficulties and misconceptions faced by the students. Every part of the ILM is intended to fulfill a particular purpose.

Table 3. Design Logic Table

Identified Difficulty	Specific Misconception/Gap	Geogebra-based ILM Feature	Purpose
1. Range of vertically shifted trigonometric functions	Students fail to adjust both minimum and maximum values after a vertical shift.	Vertical slider linked to parameter D	Allow students to observe the simultaneous upward/downward movement of the graph and correctly determine the new range.
2. Key points of the transformed cosine	Confusion in locating maxima, minima, and intercepts due to amplitude and phase shift.	Sliders for amplitude and phase shift with highlighted key points.	Visually track how points move under transformations and reinforce periodic structure.
3. Multiple transformation	Misclassification of reflection, horizontal compression, and phase shift.	Separate sliders for each parameter.	Isolate and distinguish each type of transformation clearly.
4. Tangent transformations	Misinterpretation of vertical scaling and the effect of asymptotes	Dynamic asymptote display with vertical stretch and shift sliders.	Show that asymptotes remain fixed while the graph undergoes a vertical transformation.

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5. Fractional horizontal transformations	Reversal of direction and misunderstanding of horizontal stretch/compression.	Horizontal scaling slider linked to fractional coefficients.	Demonstrate the effect of coefficients on graph stretching.
6. Reciprocal trigonometric functions	Difficulty understanding secant/cosecant and asymptotic behavior.	Simultaneous display of sine/cosine and their reciprocals with sliders.	Connect base functions with their reciprocals and visualize asymptotes dynamically.
7. Order of transformation	Incorrect sequencing of transformations.	Step-by-step slider manipulation.	Reinforce correct order and show cumulative effects of transformations

Table 3 shows that the use of a vertical slider that is directly related to parameter D directly addresses the difficulties in manipulating the minimum and maximum of a function after a vertical shift, thus enabling the students to see changes in both graph and range simultaneously. Similarly, the use of sliders for amplitude and phase shift, combined with the highlighting of important points, was done in order to resolve confusion with finding the maximum, minimum, and intercept points of a transformed cosine graph.

Moreover, the use of independent sliders for each parameter of transformation was considered based on the identified misconception in the classification of several transformations, such as reflections, horizontal compression, and phase shift. Students are expected to analyze each transformation individually to distinguish its effect before understanding the result when all the transformations are combined. The use of step-by-step slider manipulation, therefore, also takes into consideration the students' difficulties in determining the order of transformations.

For more complex trigonometric functions like the tangent function or reciprocal trigonometric functions, the ILM integrates dynamic visualization of asymptotes and graphing of multiple graphs simultaneously. The development of these two features was a response to misinterpretations of students concerning asymptotes and vertical scaling. This will enable students to recognize that although there is a transformation in the graph, key structural elements, including asymptotes, behave predictably. Additionally, the inclusion of horizontal scaling sliders with fractional coefficients addresses misinterpretations of the reversal aspect of stretches.

The design and development of the GeoGebra-based Interactive Learning Module (ILM) was informed by the principles of Backward Design, which ensures that the alignment of the content, assessment, and instruction in the ILM is appropriate and conducive to student learning in trigonometry and directly addresses the difficulties of the student.

➢ *Peer Review and Expert Validation of the Developed Geogebra-Based Interactive Learning Module*

Building on the systematic design of the GeoGebra-based Interactive Learning Module (ILM) that is based on the instructional needs identified from Phase 1 and the design features presented in Phase 2, the study progresses towards the design validation under Phase 3. At this phase, peer and expert reviews are carried out in order to evaluate the instructional validity of the developed ILM. This validation process ensures that the module is not only aligned with identified learning needs but also meets established standards for instructional design and educational effectiveness.

Table 4. Validity of the Geogebra-based Interactive Learning Module

Criteria	Peer		Expert	
	Mean	**SD**	**Mean**	**SD**
1. The Geogebra-based Interactive Learning Module (ILM) is aligned with the content of the course syllabus.	3.75**	0.452	4.00**	0.00
2. The material is appropriate for the intended target users.	3.75**	0.452	3.89**	0.333
3. The Geogebra-based ILM is suitable to the proficiency level of the target users.	3.75**	0.452	4.00**	0.00
4. The Geogebra-based ILM is relevant to the context in which it is intended to be used.	3.75**	0.452	3.67**	0.500
5. The presentation of skills in the material is appropriate to the learners' level.	3.50**	0.522	3.89**	0.333
6. The texts and exercises are relevant to the learners' needs and aligned with the course content.	3.92**	0.289	3.11*	0.333
7. The Geogebra-based ILM provides opportunities for different learning styles and supports self-directed learning.	3.33*	0.492	3.22*	0.441
8. The Geogebra-based ILM is effective in motivating learners.	3.42*	0.515	3.67**	0.500
9. Correct functioning of Geogebra simulations and interactive elements	4.00**	0.00	4.00**	0.00
10. Accurate representation of mathematical concepts	4.00**	0.00	4.00**	0.00
Overall Mean	**3.72****		**3.75****	

Legend: ***Strongly Agree(3.50-4.00), *Agree(2.50-3.49), Disagree(1.50-2.49), Strongly Disagree(1.00-1.49)*

As presented in Table 4, items 1 to 6 and 9 and 10 was rated with a range of mean score of 3.50 - 4.00 by the peer reviewers with a range of standard deviation 0.00 – 0.522, which is described as Strongly Agree, while for items 7 and 8 was rated a mean scores of 3.92(0.289) and 3.33(0.492), which describes as Agree. On the other hands, experts rated items 1 to 5 and 8 to 10 a range of mean scores 3.67 – 4.00 with a range of standard deviation of 0.00 – 0.50, which described strongly agree, while items 6 and 7 rated a mean score of 3.11(0.333) and 3.22(0.441), which described Agree. Finally, the overall mean rating of peer and expert was 3.72 and 3.75, which is described as strongly agree.

The result shows a consensus among peers and experts that the module is aligned with the course syllabus, is appropriate for the learners' level, and is relevant to the context for instructional use. Furthermore, the low standard deviation shows a high degree of consistency in the ratings by the peers and experts, which implies little variation in the evaluation of the ILM within the set of criteria. As a result, the validity results become highly reliable, which serves as an indication of the uniformity with which the ILM supports in addressing the instructional needs and achieving its intended learning outcomes of the students. Additionally, the results show that the ILM is not only user-friendly but also motivating and engaging for the learners, which is important for the success of the learning outcomes. While the peer reviewers' standard deviation is slightly larger, it means that there are small variations in the way they perceived the effectiveness of the ILM. In peer evaluations, this is a common occurrence because the reviewers have different levels of experience. Nevertheless, the standard deviation is still fairly low, which means that the differences in ratings are not substantial enough to affect the overall positive evaluation of the ILM. Furthermore, the result confirms that all evaluators are in complete agreement, proving that the interactive features, simulations, and mathematical representations used in the Geogerba-based ILM are accurate, reliable, and precise, which confirms the strength of the ILM as a correct instructional material for conceptual understanding.

This approach promotes various learning styles and self-directed learning, aligns with the findings of Ballestros et al. (2025), highlighting that through interactive learning modules, students improve their cognitive and comprehension skills.

- *Difference Between the Evaluation of Geogebra-Based Interactive Learning Module of Peer and Expert Validators.*

After the design validation phase (Phase 3), in which the GeoGebra-based Interactive Learning Module (ILM) was established to be valid in terms of content, usability, and technical accuracy, the analysis in the succeeding phase aims to further rigorously examine the consistency of the evaluations provided by the 12 peer reviewers and 9 expert validators in terms of identifying if there are significant differences in the evaluations provided. The preceding phase has already established the consistency of the ILM in meeting the required criteria in terms of high levels of agreement.

Table 5. Difference in the Evaluation of Peer and Expert.

		statistic	p	Result
Criteria	Mann-Whitney U	47	0.637	Not Significant

Note. $H_a\ \mu Peer \neq \mu Expert$

Table 5 shows that the Mann-Whitney U Test indicates that there is no significant difference in the evaluation results obtained from the peer reviewers and the expert validators to the developed ILM, as indicated by the value obtained (U/t = 47, p = 0.637).

A certain consistency in the evaluation results obtained by the peer reviewers and the expert validators. This consistency in the evaluation results further indicates that the developed ILM using GeoGebra has successfully met the intended learning objectives and is aligned with the course syllabus and the learners' proficiency levels. Most importantly, the absence of a significant difference in the results further emphasizes the credibility of the Geogerba-based ILM developed, as it demonstrates that it is has been able to cover the content in a manner consistent with the standards and guidelines followed in the development of ILMs. This consistency ensures the Geogebra-based ILM developed can be utilized across diverse classroom contexts without the concern of the different learning outcomes. Additionally, the similarities in the evaluations provided an agreement that the ILM is usable, accessible, and can support students with different capabilities and learning styles. The similarities in the evaluations provided that the module is well-designed in which it can facilitate ease of navigation, clarity of instructions, and interactive engagement. The consistency ratings indicates that the Geogebra-based ILM design can minimize the potential barriers to learning; thus, it can enhance the motivation of the students—a factor that is vital in the achievement of learning outcomes. Finally, there is a consistency in the evaluation that the accuracy and correctness of the mathematical concepts, representations, and interactive features are incorporated in the module. The accuracy of the module is essential, especially in mathematics education, as any misconception can arise from even minor inconsistencies in representation. The correctness of the graphs, simulations, and symbolic expressions ensures that students are presented with accurate mathematical concepts, thereby it enhances conceptual understanding.

It was supported by the study of Azucena et al. (2022), which states that the use of GeoGebra application helps teachers to develop various methods to promote comprehension and self-confidence in terms of mathematics among learners due to its effective instruction. Moreover, the findings of Chalaune (2020) highlighted that through Geogebra, there is a students' achievement compared to traditional teaching. These findings are consistent, indicating that the integration of GeoGebra improves mathematical learning by enhancing students' comprehension, self-confidence, and students' achievement compared to traditional teaching methods.

This implies that the strong agreement between the peer and expert validators of the Geogebra-based ILM is instructionally effective for teaching trigonometry. The alignment to the established criteria of the University can be integrated into classroom instruction to enhance students' conceptual understanding and correct misconceptions that leads to the improved students' achievement.

➢ *Pretest and Posttest Performance of the Students Before and After the Implementation of Geogebra-Based Interactive Learning Module and its Differences.*

This stage was anchored on the Development Stage, where the ILM was created with interactive features such as sliders, graphs, etc. The implementation stage then assessed the extent to which these features contributed to actual learning. The findings, therefore, were not just about the students' performance, but also about the extent to which the features of the ILM were effective in addressing the identified difficulties of the students in trigonometry.

Table 6. Pretest and Posttest Performance of the Students and its Difference.

Variables	N	Mean	SD	statistic	df	p	Result
Pretest	25	8.96*	3.12	18.3	24	<.001	Significant
Posttest	25	23.1**	2.08				

*Legend: *Below 75 (Did Not Meet Expectations), **75-79 (Fairly Satisfactory), 80-84 (Satisfactory), 85-89 (Very Satisfactory), 90-100 (Outstanding)*

Table 6 indicates that 25 students attained a mean score of 8.96 (SD = 3.12) in the pretest, which translates to Did Not Meet Expectations. Following the implementation of the GeoGebra-based ILM, the 25 students were observed to have significantly improved in their posttest with a mean score of 23.1 (SD = 2.08), which translates to Fairly Satisfactory. Additionally, from the result of the paired sample t-test, it is observed that there is a significant difference between the pretest and posttest scores of the students with a t-value of 18.3, 24 degree of freedom and p value of less than .001.

The low mean score in the pretest indicates that there was a lack of understanding of transformation among students before the implementation of the GeoGebra-based ILM. Furthermore, the high standard deviation implies variation among the prior knowledge levels of students in terms of their inconsistency in the understanding of concepts like vertical translation, identifying key points, dealing with multiple transformations, and reciprocal functions. However, the improved mean score in the posttest indicates that there was a substantial gain in the understanding of the students through the application of the ILM. Furthermore, a lower standard deviation implies that the performance of the students became more consistent, which shows that the ILM helped reduce learning gaps and supported a more equal understanding of the concept.

Furthermore, the result of the paired t-test shows that there is a significant difference between the students' pretest and posttest scores. It is therefore concluded that the performance of the students has improved significantly after the implementation of the Geogebra-based ILM. The results indicate that the ILM was effective in providing visual, interactive, and dynamic learning experiences. It was observed that the students were able to manipulate the parameters of the functions and correct misconceptions regarding the graphs of trigonometric functions. The result of the t-test shows that the Geogebra-based ILM had a significant effect on the conceptual understanding of the students regarding the transformation of the graphs of trigonometric functions, as observed in the result of the similar study done by Adila et.al (2024).

These results is in line with the study of Tamam et al. (2021), who stressed that the application of Geogebra in mathematics learning enhances students' performance by exploring, visualizing, and constructing mathematics concepts. The findings of Adila et al. (2024) and Tamam et al. (2021) are consistent with the idea that integrating Geogebra in teaching through exploration and visualization results in an improvement to the students' achievement.

This implies that the Geogebra-based ILM allowed students to explore and understand horizontal and vertical shifts, observe asymptotic behavior, and dynamic understanding of reciprocal trigonometric functions through sliders. This allowed students to have a stronger understanding of mathematical concepts.

IV. CONCLUSIONS

Based on the findings, the study concludes that the students demonstrate weak conceptual understanding of trigonometric transformations, which include the set of transformed trigonometric functions, key points, periodicity, interpretation and classification of transformations, correct order of transformations, and reciprocal trigonometric functions, indicating a need for instructional interventions such as an interactive learning module that supports visual and dynamic representation. The Geogebra-based ILM was intentionally designed and developed with its dynamic and interactive features, ensuring the alignment of the content, assessment, and instruction in the ILM is appropriate to student learning and addresses the identified difficulties of the students. Additionally, the developed Geogebra-based ILM was found to be valid and appropriate for the learners, highlighting its alignment with the course syllabus, developmentally relevant, and matches the target audience. It also applies to the instructional context, introduces skills progressively, and offers exercises that support the instructional needs of the students. Furthermore, the similar evaluation between peer and expert validators indicates that the developed Geogebra-based ILM is aligned to the content, user-friendly, and correctness of mathematical concepts. Thus, Geogebra-based ILM is found suitable for implementation.

Finally, the Geogebra-based ILM is effective as an instructional tool in enhancing the students' mathematical performance, indicating that the students correctly determine the range of the transformed function, understand how transformation affects the graph, identify the transformation and period, understand the horizontal and vertical translations of the function, and confidently identify multiple transformations.

V. RECOMMENDATIONS

The researchers recommended to develop and integrate inter active, visual-based learning tools such as GeoGebra modules specifically targeting the set of transformed trigonometric functions, key points, periodicity, interpretation and classification of transformations, correct order of transformations, and reciprocal trigonometric functions to address identified conceptual gaps. Explore the other interactive features of the Geogebra software to address other difficulties of the students in different learning areas of mathematics. Adopt the Geogebra-based ILM as an instructional resource for teaching trigonometric transformation, as it is developmentally appropriate and suitable for the target students' difficulties. Moreover, integrate the Geogebra-based ILM to support the accurate presentation of mathematical concepts, enhance learner interaction, and promote understanding through its interactive features and dynamic visualization. Make full use of the GeoGebra-based interactive learning Modules to explore and interactively manipulate the trigonometric functions, especially in terms of transformation, key points, and reciprocal functions, to improve students' understanding and performance. Lastly, conduct a similar study using a larger population or a different mathematical subject to lend more support to the efficacy of Geogebra-based ILMs and to examine other interactive features of the tool that may enhance learning outcomes.

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- *Conflict of Interest*

The authors declare no conflict of interest

- *Contributions of Individual Authors*

J.L.H. conceptualized the study, designed the methodology, and analyzed the collected data while J.P.R. assisted in conceptualization and interpretation of the data collected. The authors approved the final version of the manuscript.

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