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Impact of Phet-Based Vs. Paper-Based Trigonometric Worksheets on Students' Adaptive Thinking Skills

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ABSTRACT

Trigonometry learning often presents challenges as students struggle to apply mathematical concepts in real-world contexts. Traditional instruction tends to emphasize procedural fluency over conceptual understanding, limiting the development of students' adaptive thinking skills. Digital tools like PhET simulations offer interactive visualizations that support conceptual learning, but their role in enhancing adaptive thinking remains underexplored. This study investigates the comparative effectiveness of PhET-based worksheets versus traditional paper-based worksheets in fostering adaptive thinking in trigonometry. The study involved 80 first-year students from Universitas Serang Raya's Mathematics Education and Informatics Engineering programs, enrolled in the 2023–2024 Calculus course. Participants were divided into an experimental group using PhET-based worksheets and a control group using paper-based worksheets. Data were collected through pre-tests, post-tests, and student preference questionnaires, and analyzed using independent t-tests. Results show that the PhET group outperformed the control group, with a 35% improvement in adaptive thinking skills versus 20% in the control group ($p < 0.05$). Students using PhET-based worksheets demonstrated greater flexibility in applying trigonometric concepts, creative problem-solving, and knowledge transfer to real-life situations. In contrast, the paper-based group showed moderate gains, particularly in structured and procedural problem-solving. Questionnaire responses revealed that students appreciated the interactivity and engagement of PhET-based media, while also valuing the focus and clarity offered by paper-based worksheets. These findings highlight the potential of a blended learning approach that combines digital interactivity with structured offline tasks to enhance adaptive thinking. Future research should explore the long-term effects and broader applications of such strategies in mathematics education.

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1. INTRODUCTION

Adaptive thinking is a critical factor of high-order cognition that is vital in the mathematics learning, and specifically necessary in trigonometry. It diverges from general problem solving associated with seeking solutions to well-defined problems and from critical thinking that emphasizes logical analysis and evaluation because it allows students to flexibly adapt their reasoning strategies when encountering unfamiliar or changing problem situations (Gigerenzer, 2002; Gube & Lajoie, 2020). In trigonometry, students have to have to understand concepts such as trigonometric functions, angles, and theorems, as well as applying them in real-life situations like finding the angles of elevation, taking measurements of heights,and distances used in the construction, and in engineering (Maphutha et al., 2023; Namli, 2024). Multiple researchers indicate that adaptive thinking helps students to transfer knowledge of mathematics to different contexts, a key competency in the field of science, technology, engineering, and mathematics (STEM) (Silva Pacheco & Iturra Herrera, 2021). To develop this competence, pedagogical practices should go beyond procedural repetition, and instead focus on critical thinking, accommodation, and creative understanding that applies mathematical ideas in solving authentic problems (Sternberg, 2013; Sun et al., 2023). Such strategies are important to equip students to deal with the multifaceted problems they will likely face in the university and the workplace.

Many students of mathematics in Indonesia still struggle to use mathematics concepts (like trigonometry) to solve real-world problems. The gap in mathematical literacy levels between Indonesia and OECD countries is demonstrated by the PISA 2022 results in which Indonesia achieved a score 366 on mathematical literacy, far below the OECD average of 475, and only 18% Indonesian students are able to reach

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Level 2 proficiency against the comparable figure of 69% for the OECD countries, indicating continuous of mathematical problems such as modelling real-world situation mathematically (OECD, 2023). In the same vein, an international study, TIMSS 2019 reported underachievement by Indonesian students below the international average on solving problems including those based on geometric reasoning and the concept of functions (Mullis et al., 2019). These results stress the importance of developing instructional techniques that encourage students to apply their mathematical knowledge to real-world contexts. While trigonometry is not necessary for all students, those students who do not master it sooner will find it more difficult to master it when it comes time to study complex numbers, because they will not have made the necessary long-term connection with regular (radians) and non-regular (degrees) units of measures of angles. Full of memories of memory, many freshmen at the university stage still use it to memorize and do not form a knowledge system with both the general theory and practical application of one, can not effectively solve the problem of learning. Early interventions that develop both conceptual understanding and adaptive reasoning are consequently necessary to facilitate the transfer and application of trigonometric knowledge in academic and practical contexts.

Research evidences suggest that most students find difficulties on understanding relationship among trigonometric functions, angle measures, and the application of theorem sine and cosine in the real problem (Sholahudin & Oktaviyanthi, 2023). Due to strong dependence on rote memorization and not enough conceptual understanding, many students are unable to perform angle of elevation or depression problems (Arhin & Hokor, 2021; Sánchez et al., 2023). This problem is characteristic of a more general feature of mathematics education, the overemphasis on procedural fluency at the expense of conceptual understanding (Choppin et al., 2022). Research suggests that to learn this adaptive thinking, instructional activities that integrate conceptual knowledge with procedures would be more beneficial, which allows students to apply trigonometry more flexibly (Borji et al., 2021; Gallagher et al., 2022). The lack of educational instruments which enabled visualization and utility of this phenomenon in real life also adds to the difficulty (Maharjan et al., 2022; Ziatdinov & Valles, 2022). According to cognitive load theory, abstract mathematical ideas place a heavy burden on working memory, making visual supports essential to reduce cognitive overload and promote understanding (Sweller, 2020). In this sense, dynamic visualizations (such interactive simulations) have been identified to be more effective for enhancing concept learning than static images (Martinez et al., 2021; Yang & Chen, 2023).

To address the recurring problems in trigonometry studying, the present research investigates the impacts of two types of worksheet-based instructions PhET-based digital worksheet and traditional paper-based worksheet on promoting students' adaptive thinking capabilities. PhET is an interactive learning tool that includes visual simulation, allowing students to engage in discovery learning about important trigonometric topics, that are based on angle measures in triangles and the side relationships in triangles (Perkins, 2020). PhET encourages deeper learning and learning adaptive strategies as it physically enabled students to manipulate variables and dynamically see changes where they occurred in real time (Perkins, 2020; Giyanti et al., 2024; Wieman et al., 2010). In contrast, paper-based worksheets offer a more structured learning path, free from digital distractions, supporting sequential reasoning and in-depth problem-solving (Oktaviyanthi & Agus, 2021, 2023; Subekti & Prahmana, 2021). Research also suggests that writing by hand improves memory and cognitive activation, both of which are important for mathematical reasoning (Fanguy et al., 2023; Shi et al., 2022). Furthermore, handwritten exercises facilitate systematical thinking, which is a necessary factor for acquiring heuristic strategies in trigonometry (Ngu & Phan, 2023). So, this research examines to compare the effectiveness of medium (digital and paper) in facilitating students to master and apply trigonometric concepts meaningful to the real-life situations.

While previous research has recognised advantages of both digital and paper-based learning media digital tools such as simulations that facilitate faster learning though interactivity and paper-based materials for deeper conceptual understanding (Artasari et al., 2024; J. Lim et al., 2021; Yu et al., 2022). Nevertheless, relatively little is known about the relative merits of the two approaches in promoting adaptive thinking skills. Although some research has examined the advantages of learning with PhET simulations as compared to traditional methods, only a small number of them focused on their effects on adaptive reasoning, particularly in the trigonometry domain, which involved visual reasoning and geometric intuition (González-pérez & Ramírez-montoya, 2022; Hooshyar et al., 2020; Ngu & Phan, 2023; Silva Pacheco & Iturra Herrera, 2021). Bizami et al. (2023) conducted a meta-analysis with similar results, also stresses that hybrid approaches in which both media are combined offer the most benefit in terms of learning. Although the literature regarding the adaptive thinking has already been put into practice in contexts of algebra and calculus, it is not possible to find works that present

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its development in trigonometry. That gap is addressed in the research reported in this paper, which investigates how different instructional media (PhET-based digital worksheets and paper-based worksheets) impact students' adaptive transfer of trigonometric understanding to varied problem contexts.

Besides evaluating learning outcomes, we discuss students' experiences with the PhET and paper-based instructional materials, since engagement is a key ingredient of successful learning. Findings from studies also manifest that digital interactive tools are able to increase students' motivation and comprehensively improve students' conceptual understanding (Riyanto & Gunarhadi, 2017), and that structured paper-based activities facilitate self-regulated learning and concentrated study habits (AlGerafi et al., 2023; Eversberg & Lambrecht, 2023). Using a mixed-methods approach which incorporates both quantitative and qualitative data, the current study provides a detailed insight to how each of these media not only improves performance but also engages and supports students in problem solving in real-world trigonometric situations.

This study aims to address a key question: How is the effectiveness for the use of PhET-based worksheet, in enhancing adaptive thinking of students compare to paper-based worksheet in the trigonometry? The findings seek to contribute to instructional designs and curriculum development with regard to blended learning which has an emphasis on the degree of interactivity and structure. By doing so, the research provides insights for the design of more engaging, relevant, and effective learning media, which aims to help students develop adaptive thinking skill within 21st century digital educational context.

2. MATERIAL AND METHOD

Research Design

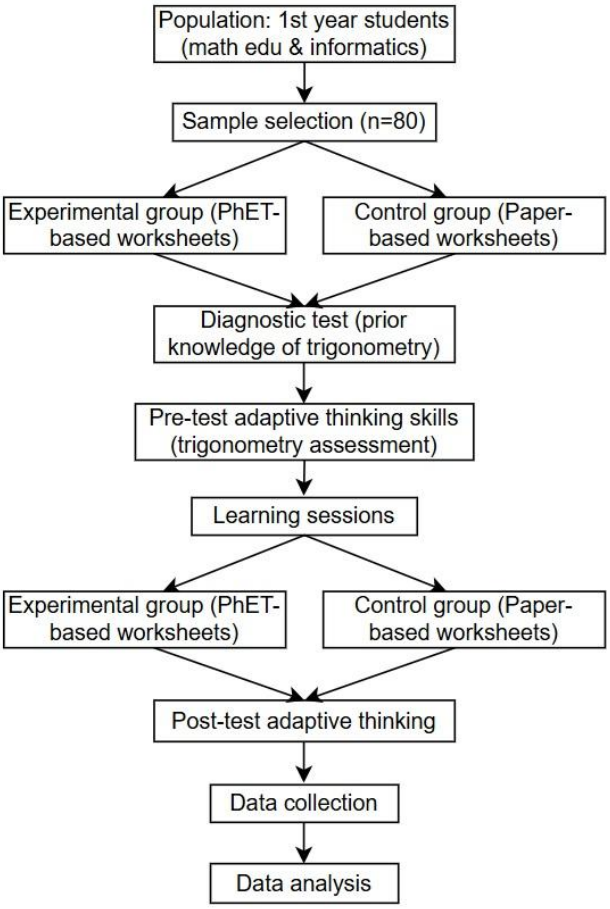

Figure 1. The Research Workflow Diagram

The study was based on comparative mixed-methods approaches to compare the effects of PhET worksheets immediately against the traditional paper worksheets on adaptive thinking skills of the students (Åkerblad et al., 2021; Creamer, 2018; Matović & Ovesni, 2023). The mixed methods were used due to their

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incorporative nature combining the use of qualitative and quantitative data, promoting triangulation, and reducing the limitations inherent to single-method analysis (Hirose & Creswell, 2023). Quantitative methods were applied to objectively measure learning outcomes, while qualitative data offered deeper insight into students' experiences and perceptions. The integration of these methods is visually represented in the research design diagram (Figure 1).

A pre-test and post-test design was utilized to evaluate changes in students' adaptive thinking skills prior to and after completion of the intervention. The pretest confirmed their initial knowledge of trigonometry and adaptive reasoning, ensuring intergroup comparability. In the course of 6 weeks, learners worked through problems with their assigned instructional materials and were taught by a single instructor to minimize instructional bias. The structurally equivalent post-test measured students' progress. The content validity was established by subject matter and evaluation exeperts to a *Content Validity Index* (*CVI*) of 0.70. *Cronbach's alpha* was used to assess the reliability, which demonstrated good internal consistency, with pre-test scores between 0.81 and post-test scores of 0.84. The test items (see Table 1) were intended to measure students' ability to flexibly apply trigonometric knowledge in authentic situations. The differences between pre- and post-test scores were then compared to assess the impact on each of the teaching treatments.

The primary intention of this study was to examine the effectiveness of PhET-based worksheets as compared to paper-based worksheets regarding adaptive thinking development of students in trigonometry. In this sense, adaptive mathematics thinking involves flexible use of trigonometric knowledge when solving reallife problems, generating alternative solution strategies, and adapting problem-solving scripts to unfamiliar challenges (Gigerenzer, 2002; Gube & Lajoie, 2020). To measure these competences were used pre and post-tests with contextualized problems of trigonometry. The PhET application was selected for its strong evidence-based framework that supports interactive learning, allowing students to manipulate variables and visualize mathematical relationships dynamically (Oktaviyanthi & Sholahudin, 2023; Teófilo De Sousa et al., 2022; Wieman et al., 2010).

Participants

The research subjects were first-year students of Mathematics Education and Informatics Engineering at universitas Serang Raya in 2023/2024 odd semester who were studying Calculus. We selected this course as it covers the fundamental concepts of trigonometry which we needed for our study. Eighty students were chosen and divided equally into two groups: an experimental group learning with PhET-based worksheets and a control group using paper-based worksheets. A power analysis was carried out to establish a reasonable sample size that delivers adequate power for statistical validity of group comparisons (Cohen, 2016; Kraemer & Blasey, 2017). The participant selection process (see Figure 2) ensured balanced prior knowledge and academic backgrounds across both groups.

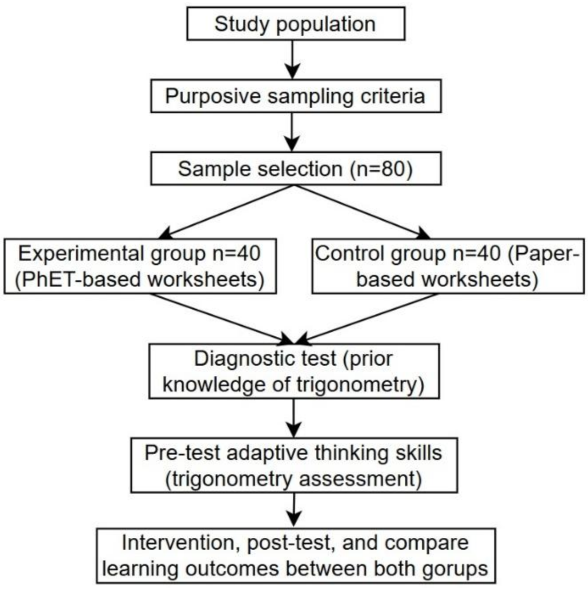

Figure 2. Participant Selection Process

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An purposive sampling approach was utilised to recruit participants that met specific inclusion criteria pertinent to the aims of the study (Cash et al., 2022). A diagnostic test was taken prior the pre-test in order to show that all students had equivalent basic knowledge of trigonometry in order to reduce source of variation. This was done to ensure that each participant was sufficiently prepared to make meaningful contributions to the teaching interventions and tasks were the focus of the study.

In this study, purposive sampling was used to control for comparability between groups by selecting students from a homogenous population—first-year students in the same Calculus course in the 2023/2024 school year. This method minimised the external variability so that variations in results could be more securely assigned to the instructional media rather than some other factor (Robinson, 2023). It also guaranteed that the students had the relevant prior experience in trigonometry which is also true of the general student population in comparable academic contexts. In doing so, the study reduced the effects of bias and confounding, improving the applicability and generalisability of the evidence (Lim, 2024; Reed et al., 2021). Criteria for this study required participants to be enrolled in the Calculus course, possess a foundational understanding of trigonometry, and commit to completing the full study process—pre-test, intervention, and post-test. To control for these confounding factors, participants were excluded if they reported having used PhET simulations previously to a great extent or had received additional instruction in trigonometry not covered in the standard high-school curriculum. This purposeful sampling approach allowed for a narrow and yet representative comparison of IM that matched the study's academic and context objectives.

Instruments and Measurement

Table 1. Examples of Pre-test and Post-test Trigonometry Problems

No.	Measured Competency	Indicator	Question Number	Difficulty Level	Problem Description
1	Understanding basic trigonometric concepts in right triangles	Students can use trigonometric ratios (sin, cos, tan) to calculate side lengths or angles.	1	Basic	A 5-meter-long ladder leans against a wall, forming a 30° angle with the ground. How high does the ladder reach on the wall?
2	Applying trigonometric concepts in real-life situations	Students can determine horizontal distances or object heights using trigonometric concepts in specific contexts.	6	Intermediate	A drone is flying at an altitude of 100 meters. From a point on the ground, the depression angle is 45°. What is the horizontal distance of the drone from this point?
3	Analyzing relationships between sides and angles in complex contexts	Students can identify and calculate side lengths or angles in non-right triangles using relevant theorems.	10	Moderately Complex	A flagpole is 9 meters tall. From a certain point on the ground, the angle of elevation to the top of the pole is 60°. What is the horizontal distance from the point to the flagpole?
4	Adapting trigonometric solutions to solve complex real-world problems	Students can calculate trigonometric values or other parameters by combining concepts and theorems.	14	Adaptively Complex	A clock tower is 30 meters tall. From two different points on the ground, the angles of elevation to the top of the tower are 30° and 45°, respectively. Determine the horizontal distance between the two points.

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The primary instruments employed in the study were the pre-tests and post-tests formulated to determine the adaptive thinking ability of students in trigonometry. The tests contained items with direct application problems of the measure of angles, calculating angles of elevation, length of horizontal distance, and the resultant usage of a relatable theorem. The instruments developed and used here were carefully structured and validated for reliability and the fit with the study purpose. Test items were developed following a comprehensive review of the literature, the curriculum, and the essential adaptive-thinking competencies. Examples of these items, along with their associated competencies, indicators, and difficulty levels, are presented in Table 1.

Table 1 provides a summary of the pre-test and post-test items that were developed to measure students' adaptive thinking skills in trigonometry. Each item was intentionally designed to test different dimensions of trigonometric knowledge and problem-solving skills for a broad measure of achievement. The table details the competencies assessed, specific indicators, problem numbers, difficulty levels, and example question prompts. The pre-test served to establish students' baseline adaptive thinking skills, while the post-test measured their development after the intervention. Both assessments included parallel items to maintain consistency and comparability across test phases. This design allowed for a targeted analysis of the instructional media's effectiveness in promoting adaptive thinking. To ensure content validity, the items were reviewed by three mathematics subject matter experts and two educational evaluation specialists. Table 2 summarizes the validation criteria and expert review outcomes.

Table 2. Validation Criteria for Content and Educational Evaluation Experts

Content Expert Validation Criteria	Educational Evaluation Expert Validation Criteria
Alignment of the problems with competencies.	Consistency of the question format (e.g., multiple-choice).
Accuracy of the answer options.	Clarity of language in the questions.
Clarity of problem formulation.	Consistency in the use of symbols and mathematical terms.
Relevance of the problems to the indicators.	Alignment of the questions with the indicators being assessed.
Logical accuracy of the answer options.	Relevance of the problems to real-life applications.
Precision in problem formulation.	Clarity of solution steps for complex problems.
Appropriateness of difficulty levels for the target competencies.	Appropriateness of rubrics for open-ended questions.
Logical reasoning in answer rationalization.	Appropriateness of difficulty level relative to the competencies.
Relevance of problem contexts to learning objectives.	Clarity of problem formulation for adaptation-based questions.
Clarity of problem formulation in the context of adaptation.	Clarity of problem formulation based on solution adaptation contexts.

Table 2 Criteria used by subject matter experts and educational evaluation experts in content validating the pre test and post test instruments. Additional reviewers Further recruited content and methodology experts performed a detailed inspection of the test and its potential items, with respect to test quality and validity. The vailidation process was to ascertain the compatibility towards intended competencies, focusing for precision, consistency and relevance. For the *CVI*, there was a 70% agreement among the experts, indicating satisfactory relevance for between items and constructs. Furthermore, a *Kappa* statistic of 0.357 was computed, indicating a moderate agreement between raters, providing additional evidence to the adequacy of the instruments.

The reliability was a pilot study carried out on 20 students outside the main sample. The internal consistency of the scores in adaptive thinking was 0.81 at pretest level and 0.84 posttest level, which represented good to very good reliability and uniformity of the measurements of the components of adaptive thinking. A preference questionnaire was also given to students in the context of the cognitive evaluations, in order to collect their impression from the two instructional modes. This tool consisted of 15 Likert scale items and 2 open-ended questions to obtain quantitative as well as qualitative information. A *Cronbach's alpha* of 0.78 was calculated,

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indicating acceptable internal consistency. The items of the questionnaire are listed in Table 3 and classified into three main dimensions: experience with PhET-based worksheets, experience with paper-based worksheets, and perception of their influence on adaptive thinking.

Table 3. Preference Questionnaire Criteria

Questionnaire Statements
A. Learning Experiences with PhET-Based Worksheets   **Statements 1–6 address indicators related to ease of use, speed, interest, and flexibility in using digital media.**
I find it easier to understand trigonometry concepts using PhET-based worksheets.
PhET-based worksheets help me solve trigonometry problems more quickly.
I feel more interested in learning using PhET-based worksheets compared to paper-based media.
PhET-based worksheets help me visualize trigonometry concepts better.
PhET-based worksheets are more flexible because they can be accessed anytime and anywhere.
Paper-based worksheets are easier to use without technical barriers.
B. Learning Experiences with Paper-Based Worksheets   **Statements 7–10 address indicators related to ease, focus, comfort, and practicality of paper-based media.**
I find it easier to understand trigonometry concepts using paper-based worksheets.
Paper-based worksheets help me focus better while learning.
I feel more comfortable learning using paper-based worksheets compared to digital media.
Paper-based worksheets are more practical and do not rely on electronic devices.
C. Impact of Media on Adaptive Thinking   **Statements 11–15 measure adaptive thinking skills influenced by the learning media.**
PhET-based worksheets make it easier for me to understand various approaches to problem-solving.
Paper-based worksheets help me better understand the steps of problem analysis.
Digital media motivate me to explore new ways of solving problems.
Paper-based media make me more systematic in solving trigonometry problems.
I feel that digital/paper media have a significant impact on my adaptive thinking skills.

Table 3 organizes the items from the questionnaire into three broad categories, which focus on assessments of different aspects of students' experiences learning and development of adaptive thinking skills using PhET-based and paper-based worksheets. The items were developed to measure different constructs such as learning ease, rate of learning, involvement, cognitive flexibility, focus, and utility. The survey also questioned the effect of each medium on students' logical and critical-thinking skills. Because of this organization, we were able to extensively evaluate both student preferences and the pedagogical value of the media employed in this study.

Research Procedure

The process of research sequence was organized to preserve uniformity and to reduce the risk of bias. First, a pre-test was given to measure the level at which students already knew trigonometric concepts and real-world-based thinking skills. According to their results, students were assigned to one of these two groups, PhET-based or paper-based worksheets, with attempts to equate previous knowledge between groups. The intervention took place over six-weeks and study participants attended structured learning sessions regardless of the study arm they were assigned to, being instructed by a single teacher to avoid bias during instruction.

Both groups followed the same basic lesson plans and teaching materials. The PhET group was exposed to interactive trigonometric simulations using computers or tablet; whereas the paper-based group used printed worksheets with comparable problems. Throughout the intervention, observers recorded students' usage of the instructional media and their problem-solving strategies.

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After the intervention, participants filled out a post-test that was the same as the pre-test to measure the effect of the training on adaptive thinking skills. They also took a preference questionnaire to give qualitative and quantitative feedback on their learning with the twoinstructional approaches.

Data Analysis

The data were analysed as mixed methods that included quantitative and qualitative methods. The independent t-test was used to compare pre- and post-test scores of between the PhET-based and paperbased groups to determine any significant difference between them (Hinton, 2014; Pham, 2023). To operate, independent t-test was opted instead ANCOVA as the two groups had similar pre-test scores, and thus satisfied the assumption of equal prior knowledge. Data analysis was carried out using SPSS, version 26, which reveals how successful the instructional media were in cultivating students' adaptive thinking skills.

On the qualitative side, students' responses from preference questionnaires and observations during the learning sessions were analyzed using thematic analOn the qualitative side, data of students' comments in preference questionnaires and in the learning sessions, have been processed through the thematic analysis (Bazeley & Richards, 2000; Elliott & Timulak, 2021; Ridder, 2014). e used this analysis to examine the perspectives and rationale of why students used PhET-based and paper-based media, and to consider the elements that affected how they learned in trigonometry. Open coding, Axial coding and theme development were employed in the thematic analysis. Emergent themes were "*Engagement in problem-solving*" and "*Perceived usability of digital media*". These qualitative results complemented the quantitative results by providing more insight into settings of preference of students and the psychological influence of the instructional media on the students' learning experiences.

3. RESULTS

Data Description

This research was conducted on 80 first-grade students in the Mathematics Education and Informatics Engineering Study Program Universitas Serang Raya, who are on the 2023/2024 academic year, determined by random sampling technique as a subject, all studied the Calculus course. A purposive sampling technique was employed to develop two groups with an equal distribution of prior knowledge and academic level. A diagnostic test was administered before the pre-test to verify that both groups had similar levels of prior knowledge of trigonometry so that any extraneous variable would not influence the results.

The experimental group, comprising 40 students, worked on worksheets embedded with PhET simulations for the topic on trigonometry. PhET was chosen because of its interactive and visual nature, which allows students to experiment with variables and dynamically explore mathematical relationships, in order to observe real-time results, a mechanism supporting the development of an adaptive form of mathematical thinking (Olugbade et al., 2024; Teófilo De Sousa et al., 2022; Wieman et al., 2010). The control group, consisting of 40 students, worked with traditional paper-based worksheets for concept and problem solving in trigonometry.

In order to make the comparison valid, both conditions received the exact same instructional material and followed the same lesson structure in the same classroom by the same teacher to reduce the likelihood of instructional bias. Additionally, a post-study questionnaire on students' motivation and user experiences of the instructional media was conducted to consider the differences in students' engagement degree. This extra assessment gave us a sense of whether engagement levels were driving the observed variances in the development of AT skills. By keeping learning conditions equivalent and by controlling for possible confounds, the study made it easier to make a reliable comparison between the PhET-based and paper-based worksheets for developing adaptive thinking in trigonometry.

Examination of Pre-Test and Post-Test Outcomes

Analysis of the Quantitative results comparing adaptive thinking of the experimental group (PhET worksheets) with control group (paper-based worksheets) is presented in this section. The assessment consists of a pre-test score, a post-test score, an improvement difference and statistical significance testing, to measure each instruction medium effect. Normality testing (*Kolmogorov-Smirnov*) revealed that pre-test scores were normally distributed for the experimental ($D(40) = 0.139, p = 0.387$) and control group ($D(40) = 0.105, p = 0.732$).

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Levene's test for equality of variances also indicated that the assumption of homogeneity had been satisfied ($F(1,78) = 0.576$, $p = 0.450$) and justifying the use of parametric statistics. Within groups, a paired sample *t-test* was performed to evaluate changes in learning from pre-test to post-test and between groups an Independent t-test was applied to compare post-test scores. Results of such analyses are listed inTable 4.

Table 4. Descriptive and Inferential Statistics for Pre-Test and Post-Test Scores

Group	Pre-test		Post-test		Mean Score Improvement	t-value	p-value	Effect Size (Cohen's d)	Remarks
	SD	Mean	SD	Mean					
Experimental Group	5.67	42.25	7.89	75.00	32.75	28.14	1.34×10^{-42}	1.84	Significant difference ($p < 0{,}05$)
Control Group	5.45	42.33	6.92	64.05	21.73				

The pre-test scores for both treatment conditions were remarkably similar (see Table 4) with the experimental condition scoring an average of 42.25 and controls 42.33. This similarity reflects a similar base of skills in adaptive thinking at the pre-intervention level. significant improvements were observed for both the teaching methodology groups after applying the pedagogic strategies. The experimental group a mean score of 75.00 as in the case of posttest and for the control group, it reached 64.05.

The experimental group performed significantly better in the post-test, indicating that the PhET-based worksheets had a greater impact on the development of students' adaptive thinking abilities. The average score improvement for the experimental group was 32.75, compared to 21.73 for the control group, indicating a greater learning gain in students exposed to digital simulation activities. Results of an independent t-test to compare post-test scores between the two groups showed a statistically significant difference ($t = 28.14$, $p < 0.05$) which meant that learning media based on PhET confidence was significantly better than traditional paper in promoting adaptive thinking skills. Moreover, the computed *Cohen's* d was 1.84, revealing a large *effect size* and highlighting the robust practical relevance of these results.

In order to visually indicate the effectiveness of the two methods, the bar graphs comparing the pre-test and post-test results of both groups can be seen in Figure 3. This is illustrated graphically in the figure which shows the significantly larger effect in the experimental group, in support of the statistical analysis, serving to highlight the larger effect of the PhET-based worksheets on students' adaptive thinking skills.

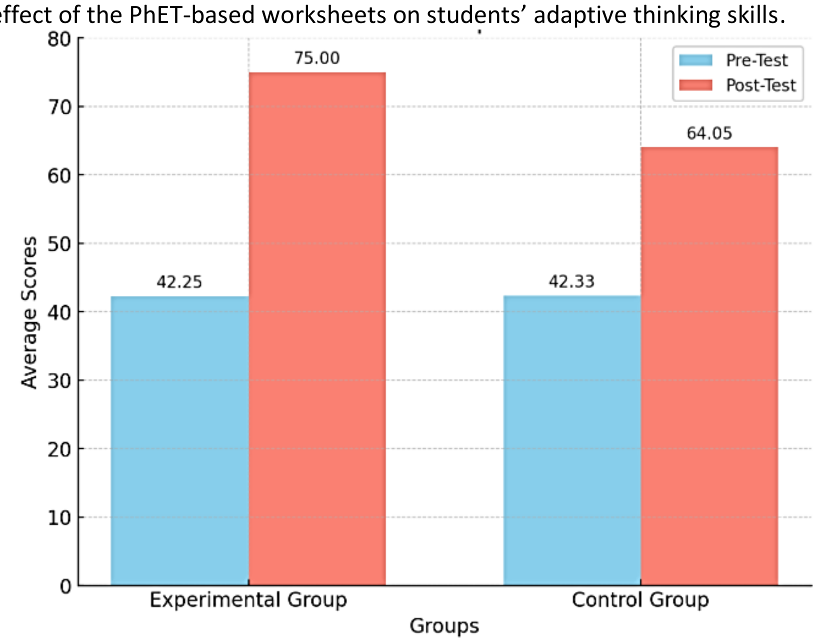

Figure 3. Pre-Test and Post-Test Score Comparison

These results are consistent with those found in earlier research on the effectiveness of PhET in promoting students' conceptual understanding, and adaptive reasoning mathematics skills (Chinaka, 2021;

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Drastisianti et al., 2024). The findings, however, are in favor of digital media and confounding variables, including differences in student interest and previous exposure to digital learning, were minimized through same instruction and balanced group assignments. However, it remains an empirical question to what extent motivational disparities in digital versus conventional learning could affect the development of adaptive thought.

Evaluation of Questionnaire Responses

The following is findings obtained from a preference questionnaire measuring students' perceptions on their learning experiences using PhET-based and paper-based worksheets in a scale of Likert. The findings were classified into the following three themes: (1) learning with PhET-based worksheets, (2) learning with paper-based worksheets, and (3) perceived effect of each medium on adaptive thinking. Table 5 offers a summary of the results, and Figure 4 shows a stacked bar chart to make the comparison of the students' responses among the three categories more evident.

Table 5. Summary of Questionnaire Results

Aspect	Key Findings	Positive Response (Skor 4/5)	Notes
A. Learning Experience with PhET-Based Worksheets			
Ease of understanding concepts	Facilitates comprehension through interactive visualization	80%	PhET visualizations aid understanding of abstract concepts like trigonometric functions
Efficiency in problem-solving	Speeds up problem-solving	75%	Simulation features shorten calculation steps
Engagement and interest	More engaging than paper-based media	85%	Students were motivated by the innovative nature of the media
Flexibility	Accessible anytime and anywhere	90%	Digital media enables usage outside the classroom
Technical challenges	Limited by device or internet issues	20% (low score)	Some students faced technical difficulties
B. Learning Experience with Paper-Based Worksheets			
Focus on learning	Helps students focus without digital distractions	70%	Suitable for in-class learning without electronic device interruptions
Comfort and practicality	Convenient use without reliance on electronic devices	75%	Students felt more relaxed using paper-based media
Conceptual understanding	Aids understanding of basic concepts but lacks support for complex visualizations	55%	Less effective for abstract concepts like trigonometric applications
C. Impact of Media on Adaptive Thinking			
Exploring diverse approaches	Digital media simplifies exploring diverse problem-solving approaches	85%	Students felt more confident trying various strategies
Systematic problem-solving	Paper-based media enhances systematic problem-solving	75%	Encourages accuracy and manual calculation detail
Motivation for creative thinking	Digital media inspires innovative problem-solving	80%	Interactive features of digital media encourage creativity

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Students' perceptions of PhET-based and paper-based worksheets are presented in Table 5. PhET-based worksheets were highly-rated as promoting concepts (80%), engagement (85%), and flexibility (90%), although 20% of students had technical problems. Paper-based worksheets, however, proved to be preferred as a source of structured problem-solving (75%) and focus (70%), but less helpful for lack of understanding (55%) because they were not interactive as visual tools are.

For clarity, a stacked bar chart comparing student responses between the two modes is shown in Figure 4. This visualisation demonstrates the corresponding strengths and weaknesses of the two methods and supports the conclusions offered in Table 5.

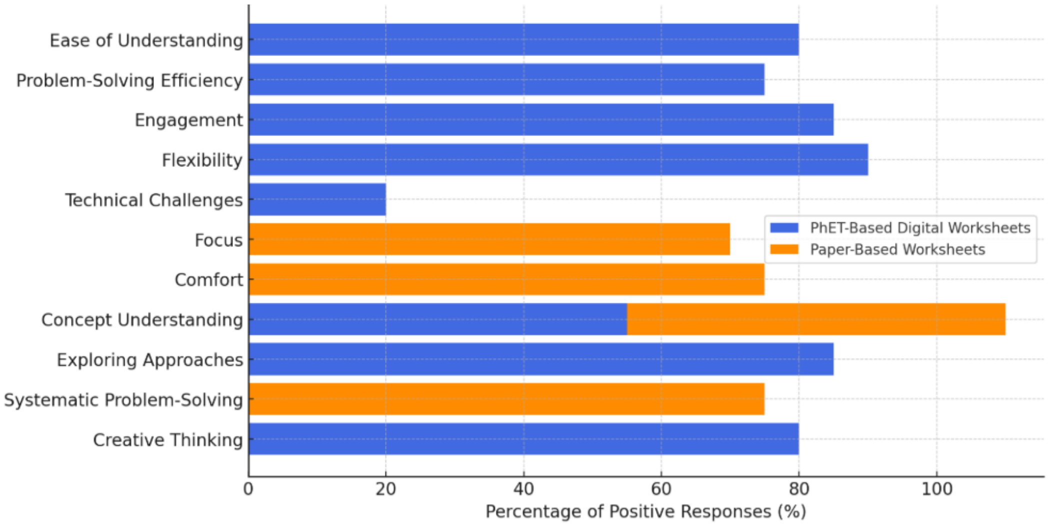

Figure 4. Comparison of Student Responses to PhET-Based and Paper-Based Worksheets

Figure 4 is comparative view of the set of responses against some of the traditional dimensions of learning. The worksheets that were designed based on PhET played an important role in making the students to be more activating and more flexible as found in studies from which underline the improvement conceptual understanding that was done using digital simulation (Martinez et al., 2021; Setiawan & Rodgers, 2024; Wang et al., 2022). However, that 20% reported technical problems suggests that while there are some improvements, access and technology reliability are still a concern. Conversely, the paper-based worksheets were more appreciated for focus on systematic reasoning and absence of distractions, which confirms the study of Eversberg and Lambrecht (2023), Stressing the importance of *procedural fluency* in traditional learning set-ups. Yet, the weaker performance in *conceptual understanding* indicates that using a paper-based approach may be less effective in supporting students to visualize complicated *trigonometric* ideas. These results suggest benefits of a *blended-model* solution—merging the interactive features of *digital media* with the organized instruction of a traditional worksheet—in order to enhance student learning.

Examination of Student Responses in Pre-Test and Post-Test Solutios

The following section offers a detailed analysis of students' responses to the pre-test and post-test questions with a specific focus on students' application of trigonometric concepts and, most importantly, their adaptive thinking about the concepts. It also gives a glimpse of the students' initial (pre-test) understanding and their subsequent progression after the treatment, using either digital media (PhET) based or traditional paper-based learning approaches. This study analyzes which extent each instructional medium influenced the students' ability to use mathematical principles in a creative and flexible manner. There are interesting trends of improvement, in the solution strategies and in the concepts learned. These changes are signals of the way in which each instructional strategy helped to foster adaptive thinking. Table 6 below provide some examples of student responses before and after the intervention, offering qualitative evidence to the basic conclusions of this study.

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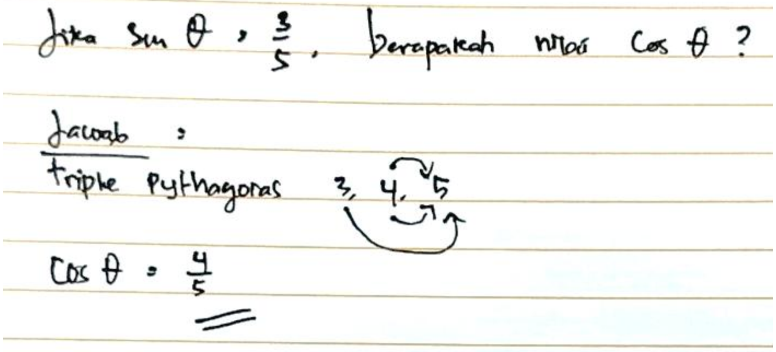
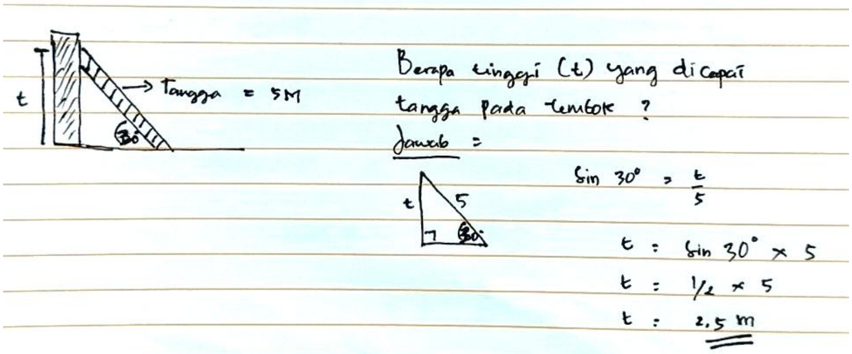
Table 6. Evaluation of Pre-Test and Post-Test Responses in the Control Group

<table>
<tr><th>Phase and Question</th><th>Subject Answer and Reasoning</th></tr>
<tr><td>Pre-test
When $\sin\theta = \frac{3}{5}$, what is the value of $\cos\theta$?</td><td>


“I recall from high school examples that if $\sin\theta = \frac{3}{5}$, then $\cos\theta$ is often $\frac{4}{5}$, because this corresponds to a triangle with sides 3, 4, and 5, which forms a Pythagorean triple.”</td></tr>
<tr><td>Post-test
A 5-meter-long ladder leans against a wall, forming a 30° angle with the ground. How high does the ladder reach on the wall?</td><td>


“To solve this, I used the concept of trigonometry, specifically the sine function, as it applies to right triangles. The sine formula states that the sine of an angle equals the proportion of the length of the opposite side to the length of the hypotenuse. From the problem, the angle is 30°, the hypotenuse is 5 meters, and the height of the ladder on the wall is the opposite side. I used the formula $\sin\theta = \frac{opposite}{hypotenuse}$, substituted the known values, and since c , the height is $\frac{1}{2} \times 5 = 2.5$ meters. The height reached by the ladder is 2.5 meters. The calculation is correct according to the trigonometric formula, and $\sin 30° = \frac{1}{2}$ is a standard value.”</td></tr>
</table>

The proportion of students in the control group who used rote learning to solve the problem was high at the pre-test as shown in Table 6. For example, one student justified the solution by an example rather than calculations, revealing a tenuous grip on the concepts of the trigonometric functions. This is the kind of rote, surface level, learning that is indicative of low-level analysis/conceptualisation. This is in contrast with the post-test responses which show greater presence of mind: the students correctly used the sine to compute the height of the ladder, which indicates they understand useful applications of the elementary trigonometric functions. Though procedural correctness was increasing, the explanation was not clear on what was being referred to by some important terms including “opposite side” and “hypotenuse”. props that paper-based instruction exhibited more rigorous and systematic thinking, but it did not help students develop precise or experimental use of mathematical language and reasoning.

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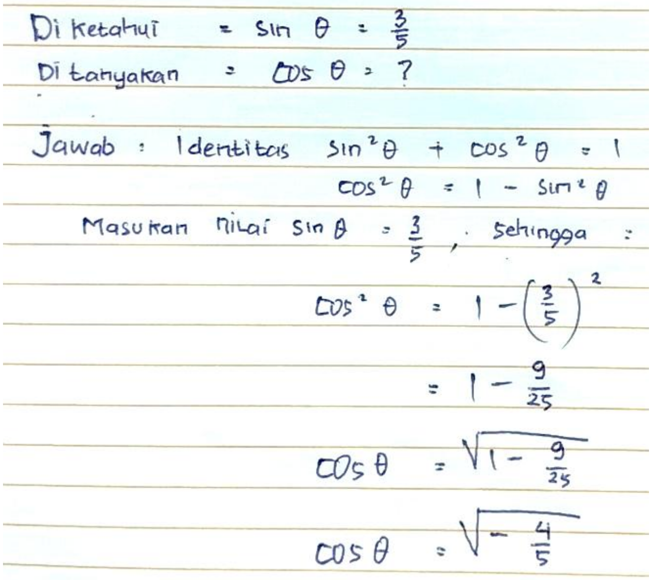
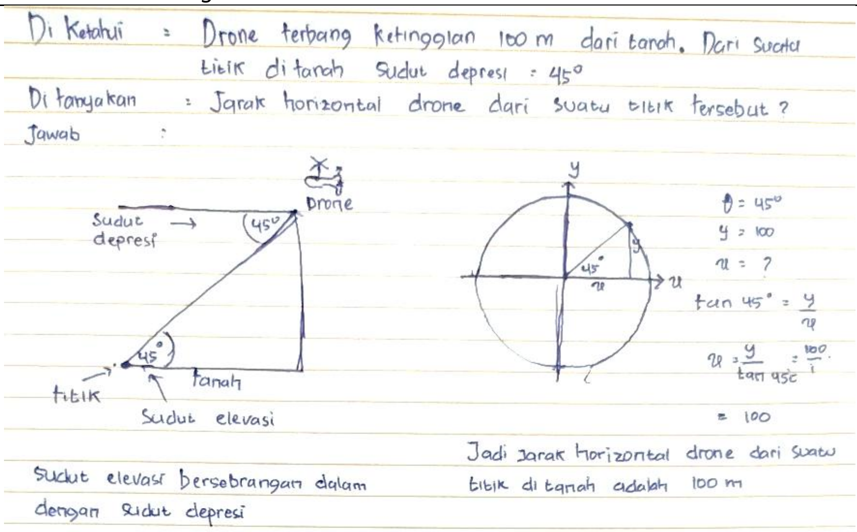
Table 7. Evaluation of Pre-Test and Post-Test Responses in the Experimental Group

<table>
<tr><th>Phase and Question</th><th>Subject Answer and Reasoning</th></tr>
<tr><td>Pre-test
When $\sin\theta = \frac{3}{5}$, what is the value of $\cos\theta$?</td><td>

"I recall that when dealing with sine, cosine, and tangent, we use the identity $sin^2\theta + cos^2\theta = 1$, substituted $sin\,\theta = \frac{3}{5}$, but after calculating $1 - \frac{9}{25}$, I got a negative result. I think this is wrong."</td></tr>
<tr><td>Post-test
A drone is flying at an altitude of 100 meters. From a point on the ground, the depression angle is 45°. What is the horizontal distance of the drone from this point?</td><td>

"In this problem, we are tasked with finding the horizontal distance of the drone from a specific point on the ground. With the drone's altitude at 100 meters and an elevation angle of 45°, I applied trigonometric principles, specifically the tangent function, which relates the ratio of the opposite side to the adjacent side in a right triangle. In this scenario, the opposite side corresponds to the drone's altitude (100 meters), and the adjacent side is the horizontal distance. Using the formula $tan\,\theta = \frac{opposite}{adjacent}$, I substituted the known values. Since $tan\,45° = 1$, I solved $1 = \frac{100}{x}$, where x is the horizontal distance. Thus, $x = 100$ meters. The horizontal distance of the drone is 100 meters. The calculation aligns with trigonometric principles, and $tan\,45° = 1$ is a recognized standard value."</td></tr>
</table>

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Based on the data presented in Table 7, the pre-test of the experimental group indicated that students could apply that basic trigonometric identity like $\sin^2\theta + \cos^2\theta = 1$, but when they executed some operations such as the subtracting of fractions in the problems, the answers generated were negative or wrong. This shows an understanding up to a point but also how they struggle when solving mathematical procedures. In the same sense, the control group students showed the same misconceptions by resorting to memorization and lacking a systematic thinking to choose and apply the trigonometric relations.

After the intervention (PhET-based worksheets), in the post-test, students of the experimental group showed more organized and articulated problem-solving strategies. The interactive simulations helped make trigonometric relationships more concrete, and easier to envision, which in turn allowed students to use functions correctly (such as employing the tangent function to solve angle of depression scenarios) and grow more confident when doing computations. However, in contrast to this, even in the control group for whom practices were better in terms of task performance, they did not indicate depth of conceptual understanding of trigonometric principles as much as their responses were more indicative of rote application/ reliance on the algorithmic process.

The effectiveness of the PhET-integrated approach is also depicted in Figure 5 where the active engagement of students in in the simulations during learning is addressed, such that digital interactivity became supportive for fostering adaptive thinking skills..

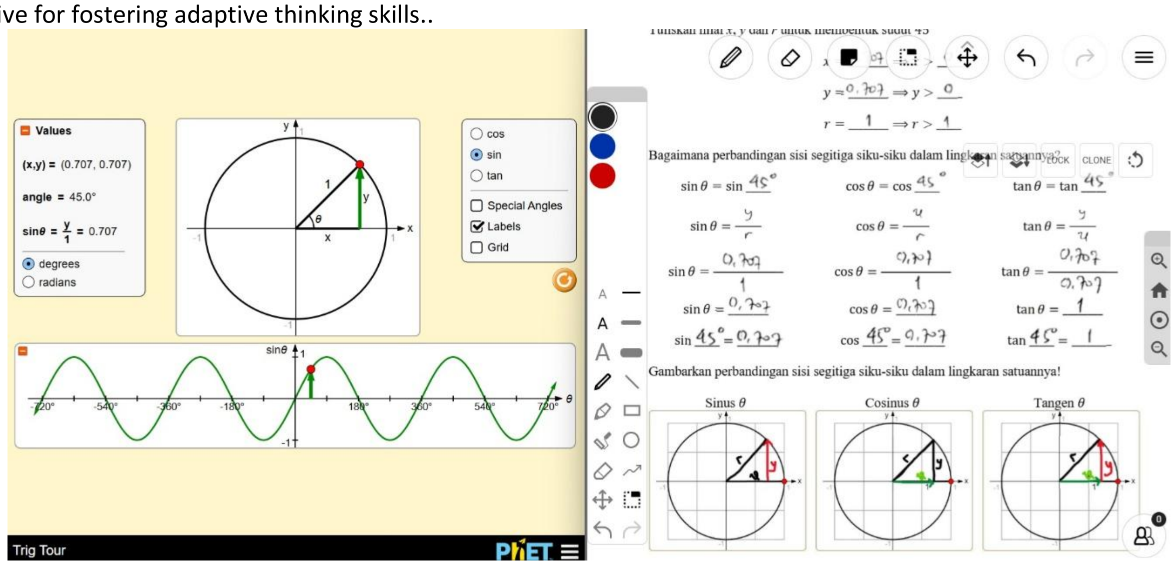

Figure 5. Student Interaction with PhET Simulations in Trigonometry Learning

Using animated visualizations of the trigonometric functions, the students could actively change the trigonometric functions to strengthen their conceptual understanding and to help with common mistakes on the pre-test—specifically, mistakes in the computation of the trigonometric identities. This hands-on strategy not only improved the precision of the procedures, but also allowed the students to relate abstract mathematical ideas to their daily lives and make sense of them. However, even more explicit attention to the clearities of mathematical reasoning (for example, defining what is meant by "*opposite side*" and "*adjacent side*") should be useful in not only achieving conceptual accuracy, but also in heading off potential misconceptions.

We conclude that PhET-based worksheets support the development of conceptual understanding whereas traditional paper-based worksheets support the consolidation of algorithmic, procedural knowledge. The potential of PhET simulations to stimulate exploratory and visual learning in conjunction with the organized practice provided by traditional worksheets is a reason for the effectiveness of a blended mode of instruction. A procedure like this could maximise conceptual and procedural learning with respect to trigonometry in a teaching and learning sense.

4. DISCUSSION

Effectiveness of PhET-Based vs. Paper-Based Trigonometric Worksheets on Adaptive Thinking

Based on the statistical analysis of the pre-and post-test data, it is concluded that the PhET-based

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worksheets promote the adaptive thinking skills of the students significantly. The experimental group increased its average score by 21.85 points as compared to the control group's 14.6. These findings indicate that the interactive and visual features of digital media better assist students in translating trigonometric knowledge into problem-solving contexts.

Adaptative thinking is especially important in trigonometry because it allows learners to use skill flexibly in non-standard situation. In contrast to traditional procedural problem solving, characterised primarily by recall of memorised formulas, adaptive thinking is conducive to encouraging perception of patterns, exploration of multiple solution methodologies, and capacity to adapt strategies to changing or diverse conditions of problems. This cognitive flexibility is necessary in real-world settings, such as in physics and engineering, where trigonometric reasoning is frequently required in dynamic and complex settings. Further statistical analysis disclosed that the *effect size* (*Cohen's d*) of the experimental group was 0.85, demonstrating a large and educationally substantial effect of the PhET-based digital worksheets on the adaptive thinking skills of students. This finding is an indication that the difference is not only statistically significant, but also meaningful in practice. As depicted in Figure 3, the bar graph comparing pre- and post-test scores clearly illustrates the greater improvement achieved by students using digital worksheets. This visual evidence reinforces the statistical findings.

A possible reason (good cause) for this success is the interactive character of PhET simulations. These functionalities allowed students to interact with variables, make sense of relationships, and get immediate feedback, promoting discovery learning and early adoption of flexible problem-solving approaches. On the other hand, pencil and paper-based worksheets did not have these interactivity features, which reduced the chance of exploring and adapting ideas during problem-solving activities. The effectiveness of PhET in enhancing students' understanding of trigonometric concepts is consistent with recent research in the field of multimedia learning (e.g., Olugbade et al., 2024; Teófilo De Sousa et al., 2022), which highlighted the importance of interactive visualizations in developing mathematical understanding. Trigonometric subject matter— most notably the unit circle and the concept of angle— are by nature abstract, and are inherently challenging to learn through static renderings alone. Dynamic PhET simulations allow students to see how changes in angle measures and side lengths effect ratios, which helps to develop students' spatial reasoning and conceptual understanding. These suggestions can be reinforced by Mayer's Multimedia Learning Theory (2017), who states that when visual and verbal cues are integrated then the learning transactions are more effective because learning is promoted through two-channel processing simultaneously. This principle is exploited by the PhET simulations through the interactivity, which is utilized to decrease the cognitive load and enables the students to cognitively process the complex concepts of trigonometry more easily and meaningfully.

However, it is proposed by *Cognitive Load Theory* that too much extraneous cognitive load impairs learning(Sweller, 2011, 2020). Although PhET's simulations supported conceptual understanding, some students had difficulty interacting with digital resources and multitasking and could experience cognitive overload. This supports Weng et al. (2023) and Molina Roldán et al. (2021) results that interactive settings facilitate deep learning, they may impose a burden on those students with weaker digital skills. Paper-based worksheets, on the other hand, offered a deliberately curated learning environment that was free from distractions, thus not only allowing student to solve problems step by step but to focus on it better.

Student Perceptions and Learning Preferences

These results are further supported by the questionnaire responses. Eighty-five percent of students in the experimental group found that digital media increased their participation in the learning task (engagement), and 75% participants in the control group chose the paper printed worksheet as their favorite because it was more explicit and stable. These findings are in agreement with the work of Makransky and Mayer (2022), who demonstrated that interactive simulations significantly increase students' engagement and their conceptual understanding in STEM education. Similar to our study, they noted students learning from dynamic visualizations in order to develop a visual understanding of abstract mathematical concepts. It was revealed that PhET's interactive features promoted students' interaction that led to greater students' engagement and creativity in resolving problems, which supported the constructivist learning theories (Piaget & Vygotsky) (Satria et al., 2024;

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Winarno & Legowo, 2024). Through actively investigating different mathematical representations students developed their adaptive reasoning. Nevertheless, the information showed us that some students not as digital proficient tended to struggle with navigating the PhET simulations which made them feel frustrated and made the learning less effective. This result indicates that experience of digital tools used in this study may be one of the factors that affect how effective these platforms are for certain types of learners.

As for types of problem-solving strategies, experimental students were also more likely to attempt trial-and-error investigation and hypothesis testing, exploiting the opportunity of instant feedback from PhET. Students who worked on paper-based worksheets instead mostly used pattern recognition and procedural repetition to solve trigonometry tasks. This inconsistency may indicate that digital tools promote an exploratory and flexible strategy of problem-solving, as well as structured and systematic thinking. Vygotsky's scaffolding is particularly applicable in PhET-based learning environments. In these environments, students experience a feed-back on their process and a guided exploration that serve as scaffolds that help them during the searching process. This is consistent with Vygotsky's claim that student growth is greatest with dynamic support that is reduced as competence increases. PhET's interactivity acts as a type of digital scaffolding in that it allows students to make predictions, refine their understanding, and iterate on their learning. Further, 80% of the students in the experimental group enjoyed the convenience of digital media that enabled them to learn materials everywhere and at all times. But digital access and equity are still major challenges. Müller and Mildenberger (2021) underline the potential for the digital divide and unstable internet access to widen educational inequality in less-advantaged educational contexts. It is important that such challenges are taken into consideration when incorporating digital learning approaches. Because digital and paper-based learning media have different strengths and weaknesses, a combination of the two may be the best way to improve adaptive thinking ability among students. Using the digital simulation based on the PhET description creates an interactive and inquiry learning space which allows students to explore conceptual understanding and the traditional paper based worksheets support the structured practice and procedural fluency (Lestari et al., 2018). For better learning efficiency, digital media might be used at the beginning of a course to let students interact with reality simulations to visualize the relationship of trigonometry. This reflects the constructivist theory view that learning enables us to be active participants in knowledge construction.

Paper-based worksheets can then consolidate these ideas by walking students through step-by-step problem-solving activities, and helping to reduce cognitive load and consolidate the students' understanding. Further, when taking personal learning preferences into account, the hybrid use of both approaches allows students to enjoy the interactive, adaptive affordances that digital tools provide, balanced with the clarity and organization provided through traditional worksheets. Through the hybrid approach, teachers should be able to build a more balanced and inclusive classroom and to address diverse students the needs thereby fostering both creativity and thinking in the trigonometry learning process.

5. CONCLUSION

This study contrasts the effects of PhET activities and paper-based worksheets to promote students' adoption for trigonometry, emphasizing superiority of the use of digital media. Unlike previous investigations, which have primarily emphasized engagement and concept understanding, this study directly considers the effect on adaptive ability. The experimental group taught by PhET-based worksheet performed the significant difference in the post-test scores (+21.85) to the control group (+14.6) with the effect size = 0.85 representing the great educational impact. These results imply that trigonometry teaching should incorporate digital simulations to enable students to be more flexible at problem-solving and generalize to the real world. More able students accessing digital media showed greater transfer, problem- solving in novel situations, and flexible ways of reasoning. They were more involved in trial-and-error experimentation, hypothesis generation and dynamic visualisation to consolidate their learning, through interactive feedback. However, paper based media still has its lead in structure, attention of focus, and accessability which still applies to preparation for exams and students with limited digital access. For some students, the ease-of-use of learning on paper, and its agnosticism towards technical issues, is what they liked.

A mixed model that takes the best of both types of media can potentially enrich the learning experience. To enable to interactive exploration, concepts can be introduced through digital media while procedural fluency and generalised problem solving can be practiced through paper-based worksheets. This hybrid model of exploration and instruction is consistent with *constructivist theory*.

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Based on these results, it is suggested that trigonometry should be taught using the blended learning approach. Digital media serves as a tool for concept introduction and interactive exploration, with paper-based worksheets providing practice in a more structured setting. This method achieves engagement, clarity and real abstraction. In the future, the effectiveness of other platforms (e.g., GeoGebra, Desmos) or AI-based tutoring and gamification of digital learning could be studied. Future studies may speculate as well on adaptive thinking in cross-disciplinary disciplines as physics or engineering, widening its potential application.

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