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The effect of mobile seamless inquiry media on conceptual mathematics learning outcomes in trigonometry

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Abstract. The abstract nature of mathematics concepts and limited class time are key factors contributing to low conceptual mathematics learning outcomes. This issue is evident among eleventh-grade students at SMA Negeri 4 Singaraja, who have difficulties in learning abstract topics such as trigonometry. This study investigates the effect of implementing Mobile Seamless Inquiry Media (MoSIM), a digital learning strategy designed to support Inquiry-Based Learning (IBL) anytime and anywhere, on students' conceptual mathematics learning outcomes. A quasi-experimental pretest-posttest non-equivalent control group design was employed, involving 185 eleventh-grade students selected from a population of 301 students at SMA Negeri 4 Singaraja using cluster random sampling. Conceptual learning outcomes were measured using a validated multiple-choice test and analysed through one-way ANCOVA. The results revealed a statistically significant difference between students taught using the MoSIM strategy and those taught using conventional strategies ($F = 5.84$, $p = 0.01$). Students who learned through MoSIM achieved higher adjusted post-test scores ($M = 80.03$; $SE = 1.03$) compared to those who learned through conventional strategies ($M = 76.57$; $SE = 0.99$). These findings recommend the integration of MoSIM into digital era learning environments to enhance students' conceptual mathematics learning outcomes, especially in complex and abstract topics like trigonometry.

Introduction

Mathematics plays a pivotal role in developing students' reasoning, critical thinking, and problem-solving abilities (Andrews-Larson et al., 2021; Duran & Dökme, 2016; Kevin A. Artuz & B. Roble, 2021). Among its core components, conceptual knowledge is widely recognised as essential for long-term learning and transfer of knowledge (Mendezabal & Tindowen, 2018; Rittle-Johnson & Siegler, 2022). However, recent international assessments, such as PISA, reveal that many students continue to struggle with conceptual mathematics learning outcomes, especially in complex topics like trigonometry. Indonesia's average PISA mathematics score in 2022 was 366, far below the international average of 472, with over 80% of students performing below proficiency level 2 (Kemendikbudristek, 2023; OECD, 2023). These findings highlight the urgent need to rethink instructional strategies that effectively foster conceptual learning in mathematics classrooms.

Trigonometry is one of the fundamental mathematical concepts that serves as a critical foundation for advanced studies in mathematics, physics, engineering, and other applied sciences (Widana et al., 2024). Yet, despite its importance, difficulties in learning trigonometry remain a persistent challenge for many students. They often struggle to connect graphical and algebraic representations of trigonometric functions (Hidayat et al., 2023), leading to fragmented understanding and rote-based learning. Misinterpretations also arise when students view sine and cosine functions solely in the context of triangles, rather than as continuous functions defined over the unit circle and applicable across various quadrants (Kamber & Takaci, 2018). In addition, many students misunderstand the role of radians in measuring angular displacement, which further hampers their comprehension of the periodic nature of trigonometric graphs (Bekene Bedada & Machaba, 2022). These conceptual gaps hinder students' ability to generalize and apply trigonometric knowledge not only within mathematical problem-solving but also in interpreting real-world phenomena involving periodic patterns. As a result, a disconnect often emerges between students' procedural fluency, such as solving standard exercises, and their deeper conceptual understanding, thus limiting their capacity to transfer knowledge across topics and disciplines (Sukendra et al., 2023).

As part of a preliminary study aimed at exploring students' perceptions of learning mathematics, a total of 35 randomly selected eleventh-grade students at SMA Negeri 4 Singaraja completed the Mathematics Perception Scale questionnaire, consisting of 32 statement items administered online via https://bit.ly/skala-persepsi. One key result showed an average score of 2.58 (on a 1–5 scale) for their self-assessed conceptual knowledge of mathematics, indicating a poor level. This finding confirms the observed gap in students' conceptual mathematics learning outcomes and reinforces the urgency for more effective teaching strategies tailored to their needs (Juniantari et al., 2025).

Conventional teaching strategies, which emphasise memorisation and procedural practice, tend to reinforce shallow learning and limit students' conceptual development (Cavey & Berenson, 2005; Nanmumpuni & Retnawati, 2021). Students may recall formulas but fail to understand the underlying principles, resulting in fragmented knowledge that is difficult to apply in problem-solving situations. Conceptual learning outcomes in mathematics are generally indicated by students' ability to analyse relationships between concepts, identify examples and non-examples, and formulate concepts into various representations (Kilpatrick & Swafford, 2001). Thus, improving students' conceptual outcomes requires instructional strategies that go beyond rote practice and instead promote active and meaningful learning (Rittle-Johnson & Siegler, 2022).

Technology-enhanced learning environments, such as GeoGebra and interactive simulations, have been shown to improve students' visualisation and comprehension of trigonometric concepts (Nanmumpuni & Retnawati, 2021; Zamorano Urrutia et al., 2019; Widana & Laksitasari, 2023). However, disparities in digital infrastructure and access can limit their widespread use. An alternative and promising model for addressing conceptual difficulties is Inquiry-Based Learning (IBL), which encourages students to observe, question, hypothesise, explore, and reflect (Andrews-Larson et al., 2021; Gómez-Chacón et al., 2021; Narta, 2022). This student-centred model aligns with the indicators of conceptual learning outcomes and helps students build coherent and transferable knowledge structures, supporting their ability to apply mathematics in diverse contexts.

Empirical studies support the benefits of IBL in mathematics classrooms, including enhanced engagement, deeper understanding, and improved metacognitive skills (Abdurrahman et al., 2021; Gómez-Chacón et al., 2021). Despite these advantages, full implementation of IBL is often hindered by rigid curricula, limited classroom time, and teachers' preparedness (Loizou & Lee, 2020; Schallert et al., 2022). These constraints often prevent teachers from facilitating the full cycle of inquiry, especially in content as dense as trigonometry. To overcome these challenges, the integration of digital learning technologies into IBL environments is gaining attention as a viable solution that offers flexibility and extended learning opportunities.

One such innovation that responds to the challenges of conceptual mathematics learning is the Mobile Seamless Inquiry Media (MoSIM) strategy, which purposefully integrates the inquiry learning process with the affordances of mobile seamless technology. This strategy enables students to engage in learning activities both inside and outside the classroom, bridging formal and informal settings through the use of digital media that is accessible via personal mobile devices. By leveraging the 5E instructional model: engage, explore, explain, elaborate, and evaluate. MoSIM supports structured inquiry while removing spatial and temporal barriers that often restrict deep learning in traditional settings (Juniantari et al., 2025; Safiah et al., 2020). Each phase of the model is embedded with interactive tasks that promote curiosity, exploration, and reflection, thereby encouraging students to construct their understanding gradually and meaningfully. The core objective of MoSIM is not merely to digitize content but to cultivate learner autonomy by enabling students to take ownership of their inquiry, revisit complex concepts at their own pace, and engage in cognitively demanding tasks beyond the limited time of classroom instruction. This approach aligns well with the demands of 21st-century mathematics education, which calls for flexibility, contextual learning, and deep engagement with content.

The MoSIM framework is grounded in the ten dimensions of Mobile Seamless Learning (MSL), such as formal and informal (MSL 1), personal and social (MSL 2), cross-time (MSL 3), cross-location (MSL 4), real-time information (MSL 5), physical and digital worlds (MSL 6), various types of devices (MSL 7), different learning tasks (MSL 8), knowledge synthesis (MSL 9), and various stages of learning models (MSL 10) (Hendrowibowo & Kristanto, 2023; Moon et al., 2023; Ulfa et al., 2020). These dimensions allow learning to occur in authentic contexts and to be sustained over time. Designed using the eXeLearning platform, MoSIM includes modules, videos, worksheets, and GeoGebra that support inquiry activities both synchronously and asynchronously. This flexibility allows students to build conceptual knowledge in trigonometry at their own pace and in their context, enabling deeper exploration and personalised learning pathways.

This study builds upon prior research that introduced MoSIM as a strategy to support conceptual mathematics learning in the digital era (Juniantari et al., 2025). While previous work focused on its design, the present study examines its empirical effect in a real classroom setting to determine the effect of the MoSIM strategy on students' conceptual mathematics learning outcomes in the topic of trigonometry. Accordingly, the research question is: Is there a significant difference in conceptual mathematics learning outcomes between students who learn using the MoSIM strategy and conventional strategies? To address this question, the following hypotheses are proposed. (H_0): There is no significant difference in conceptual mathematics learning outcomes between students who learn using the MoSIM strategy and conventional strategies; (H_1): There is a significant difference between the two groups.

Method

This study employed a quasi-experimental pretest-posttest non-equivalent control group design, commonly used in field-based educational research to compare instructional interventions (Purnomo et al., 2025; Santyadiputra et al., 2024; Tuckman & Harper, 2012). The population consisted of 301 eleventh-grade students at SMA Negeri 4 Singaraja, Bali Province, Indonesia, during the 2024/2025 academic year. From this population, 185 students were selected as research subjects using cluster random sampling. They were spread across six classes: three classes (92 students) in the experimental group using the Mobile Seamless Inquiry Media (MoSIM) strategy, and three other classes (93 students) as the control group using conventional strategies with student worksheets. The study was conducted during the odd semester of the 2024/2025 academic year, from August to October 2024.

Data on students' conceptual mathematics learning outcomes were collected using a pretest-posttest technique. The instrument consisted of 36 multiple-choice items developed based on three core indicators: (1) analyzing relationships between concepts, (2) identifying examples and non-examples of a concept, and (3) representing concepts in various forms (Kilpatrick & Swafford, 2001). These items were organized across four main trigonometry content areas: the unit circle, trigonometric function graphs, trigonometric identities, and the sine and cosine rules. Table 1 presents the instrument's structure, highlighting the alignment between content areas, cognitive levels, and item distribution.

Table 1. Conceptual Mathematics Learning Outcome Test Instrument

Contents	Learning objectives	Cognitive levels	Question items
Trigonometry and the unit circle	Students can analyse the relationship between trigonometry function concepts using the unit circle.	C4	Q1, Q4, Q7
	Students can identify examples and non-examples of trigonometry function concepts.	C5	Q2, Q5, Q8
	Students can formulate trigonometry functions into various representations.	C6	Q3, Q6, Q9
Trigonometry function graphs	Students can analyse the relationship between trigonometry function graph concepts.	C4	Q10, Q13, Q16
	Students can identify examples and non-examples of trigonometry function graphs.	C5	Q11, Q14, Q17
	Students can formulate trigonometry functions into various representations based on the trigonometric graphs provided	C6	Q12, Q15, Q18
Trigonometry Identities	Students can analyse the relationship between trigonometry identity concepts.	C4	Q19, Q22, Q25
	Students can identify examples and non-examples of trigonometry identities.	C5	Q20, Q23, Q26
	Students can formulate trigonometry identities into various representations.	C6	Q21, Q24, Q27
Sine and Cosine Rules	Students can analyse the relationship between trigonometry concepts in the sine and cosine rules.	C4	Q28, Q31, Q34
	Students can identify examples and non-examples of problems that can be solved using the concept of the sine and cosine rules.	C5	Q29, Q32, Q35
	Students can formulate the sine and cosine rules into various representations.	C6	Q30, Q33, Q36

The 36-item instrument was evaluated for content validity by two subject-matter experts using a 5-point Likert scale. Items that met the minimum content validity criterion ($M > 3.40$) were subsequently tested for construct validity using corrected item-total correlation and for reliability using Cronbach's alpha. Items were considered valid if the corrected item-total correlation exceeded the r-table value (0.301), and the instrument was deemed reliable if the Cronbach's alpha coefficient was greater than 0.70.

The pretest and post-test data were analysed using a one-way analysis of covariance (ANCOVA) to test the null hypothesis (H_0): There is no significant difference in conceptual mathematics learning outcomes between students who learn using the MoSIM strategy and conventional strategies; (H_1): There is a significant difference between the two groups. Before ANCOVA, assumptions of homogeneity of variances and normality were tested. If both were satisfied ($p > 0.05$), ANCOVA was conducted. The null hypothesis was accepted if $p > 0.05$ and rejected if $p < 0.05$.

This study employed an experimental procedure, as shown in Image 1, which was implemented over eight class sessions, each lasting 80 minutes. In the first session, students completed a pretest and received a brief orientation to the course objectives. In addition, the pretest scores were analyzed to confirm that the experimental and control groups were equivalent before the instructional intervention. Instructional interventions were conducted in sessions two through seven. The experimental group used MoSIM to engage with content both inside and outside of class, while the control group used printed worksheets under teacher guidance. In the eighth session, all students completed a post-test and provided written feedback about their learning experience. This structure helped ensure that instructional time and topic coverage remained equivalent across both groups, with the main distinction being the learning strategy. Different teachers taught the experimental and control classes, but both held equivalent academic qualifications and teaching experience in mathematics. Their equivalency was reviewed through internal school records and coordinated in lesson planning to minimize instructional bias.

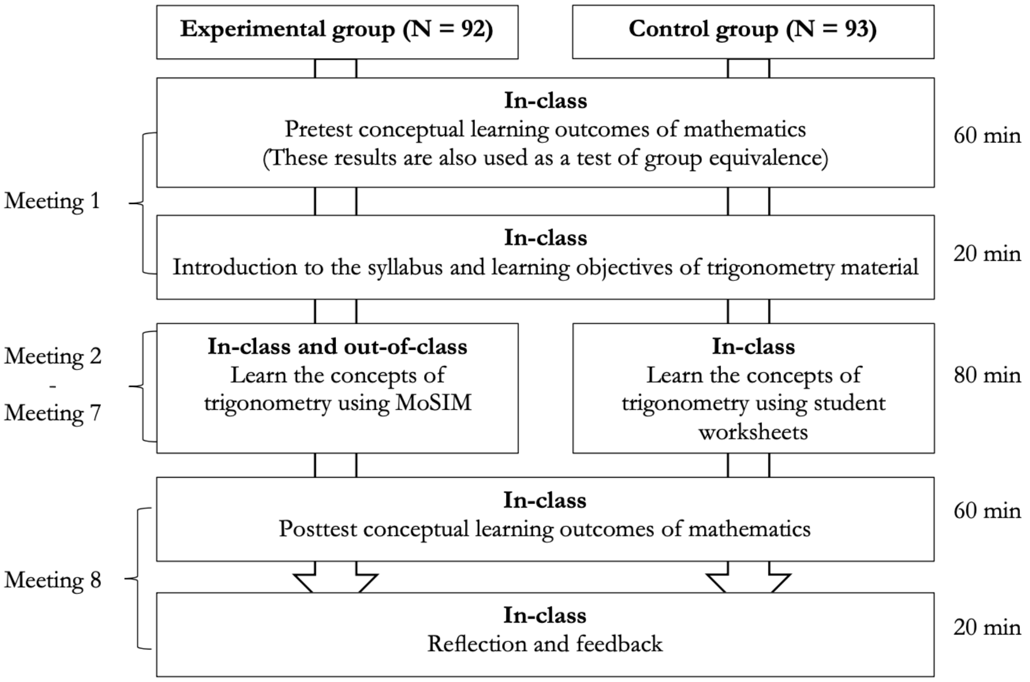

Image 1. Experimental Procedure

To ensure internal validity, both groups received the same learning time, material coverage, and a validated and reliable test of conceptual understanding. A pretest was also conducted to check for initial differences. External validity was supported by using a representative sample ($n = 185$) to represent populasi. Before ANCOVA was performed, tests for homogeneity and normality were carried out and met the required criteria, ensuring that the results can be generalized to the population.

Results and Discussion

To ensure measurement accuracy and relevance, a 36-item multiple-choice test on conceptual mathematics learning outcomes was evaluated for content validity, construct validity, and reliability. Expert judgment indicated a very high level of content validity (M = 4.77). For construct validity, the test was administered to 43 twelfth-grade students from the same school. The corrected item-total correlation analysis revealed that six items scored below the r-table threshold (0.301) and were deemed invalid. Consequently, 15 valid items were selected to represent the key indicators of conceptual learning outcomes. The correlation values of these 15 items are presented in Table 2.

Table 2. Results of the Validity Test for 15 Question Items

Question items	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Q1	0.53	0.80
Q2	0.36	0.82
Q6	0.47	0.81
Q10	0.60	0.80
Q11	0.48	0.81
Q12	0.36	0.81
Q14	0.36	0.81
Q19	0.32	0.81
Q20	0.56	0.80
Q21	0.47	0.81
Q22	0.35	0.81
Q28	0.53	0.80
Q29	0.31	0.82
Q30	0.46	0.81
Q31	0.38	0.81

The overall Cronbach’s Alpha for the instrument was 0.82, which indicates high reliability and suggests that the items were internally coherent in measuring the targeted construct. This strong reliability supports the validity of the conclusions drawn from students’ performance data. The consistent measurement across items ensures that the test accurately reflects students’ conceptual mathematics learning outcomes in trigonometry.

Descriptive statistics were analysed to provide an overview of student performance before and after the intervention. Table 3 presents the mean scores, standard deviations, and standard errors of both pretest and post-test results for students in the MoSIM and conventional groups. The descriptive data offer initial insights into the comparative performance of the two instructional strategies. While the pretest means were relatively close between groups, indicating comparable baseline knowledge, the post-test scores reveal a more pronounced difference.

Table 3. Descriptive Statistics of the Mean Pretest and Posttest

Variables		N	M	SD	SE
Pretest	MoSIM	89	53.71	17.33	1.84
	Conventional	96	49.86	16.86	1.72
	Total	185	51.71	17.15	1.26
Post-test	MoSIM	89	80.60	9.57	1.01
	Conventional	96	76.04	11.83	1.21
	Total	185	78.23	11.01	0.81

The pretest mean for the MoSIM group was 53.71, which was slightly higher than the 49.86 recorded by the conventional group, indicating a modest initial difference in students' conceptual learning outcomes. However, the post-test results revealed a more substantial gap between the two groups. Students in the MoSIM group achieved an average post-test score of 80.60, whereas those in the conventional group attained a mean score of 76.04. This difference suggests a potentially greater effectiveness of the MoSIM strategy in enhancing conceptual mathematics learning outcomes. Nonetheless, to establish whether this observed improvement was statistically significant and not merely pre-existing disparities, further inferential statistical analyses were carried out.

To verify the assumption of group equivalence at baseline, Levene's test for homogeneity of variances was conducted on pretest data. Table 4 presents the results, indicating no significant difference in variance between the groups ($p = 0.98$). Additional assumption tests were also carried out, including Levene's test on post-test data and tests for normality using Kolmogorov-Smirnov and Shapiro-Wilk methods. These results are shown in Table 5 and Table 6, respectively.

Table 4. Homogeneity of Pretest Data Using Levene's Test

Levene Statistic	df1	df2	p-values
0.001	1	183	0.98

Table 5. Homogeneity of Posttest Variance Using Levene's Test

Levene statistic	df1	df2	p-values
2.38	1	183	0.12

Table 6. Normality of Unstandardized Residuals Test Using Kolmogorov-Smirnov and Shapiro-Wilk

Kolmogorov-Smirnov			Shapiro-Wilk		
Statistic	df	Sig.	Statistic	df	p-values
0.05	185	0.20	0.99	185	0.68

The assumption tests confirmed that the data met the criteria for parametric analysis. Consequently, ANCOVA was used to control for initial differences in pretest scores and isolate the effect of the MoSIM strategy compared to conventional instruction on students' post-test performance.

Table 7 presents the outcome of the ANCOVA. The analysis revealed a statistically significant effect of the instructional strategy on students' conceptual mathematics learning outcomes ($F = 5.84$, $p = 0.01$), with an adjusted R^2 value of 0.23. This means that approximately 23% of the variance in post-test scores can be attributed to the learning strategy, independent of initial differences. These results address the research question by rejecting the null hypothesis (H_0), thereby confirming that there is a significant difference in conceptual mathematics learning outcomes between students who learned using the MoSIM strategy and those who learned through conventional strategies.

Table 7. ANCOVA Result for Student's Conceptual Learning Outcomes

Source	Type III Sum of Squares	df	Mean Square	F	p-values
Corrected Model	5354.90*	2	2677.45	28.74	0.00
Pretest	4395.41	1	4395.41	47.17	0.00
Strategy	544.35	1	544.35	5.84	0.01

***R^2 = 0.24 (Adjusted R^2 = 0.23)**

To further interpret this result, estimated marginal means were calculated. These values, shown in Table 8, represent the adjusted post-test scores for each group after accounting for pretest performance. The MoSIM group achieved a higher adjusted mean score (M = 80.03; SE = 1.03) compared to the conventional group (M = 76.57; SE = 0.99), indicating a clear advantage of the MoSIM strategy.

Table 8. Estimated Marginal Means

Strategy	M	SE
MoSIM	80.03*	1.03
Conventional	76.57*	0.99

***Covariates appearing in the model are evaluated at the following values: pretest = 51.7118.**

Image 2 visually illustrates this difference in post-test performance between the groups. The plot highlights the effectiveness of MoSIM in improving conceptual mathematics learning outcomes through its structured and inquiry-driven design. Image 2 visually illustrates the difference in posttest performance between the experimental and control groups. The plot shows that students who learned using the MoSIM strategy achieved higher estimated marginal means compared to those taught through conventional methods. This difference reinforces the effectiveness of MoSIM in enhancing students' conceptual mathematics learning outcomes, particularly in trigonometry.

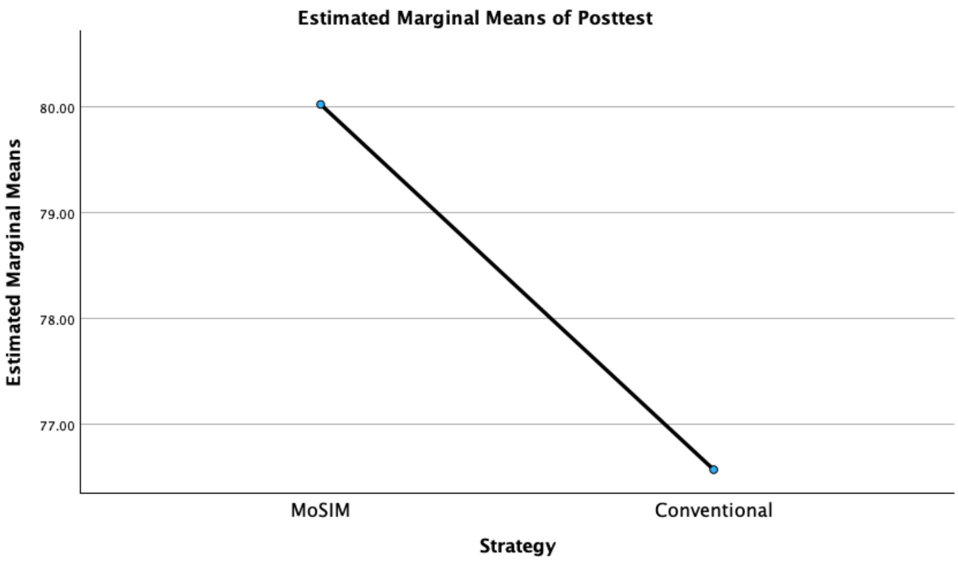

Image 2. Plot of Estimated Marginal Means

These findings support the conclusion that the MoSIM strategy is effective in enhancing students' conceptual learning outcomes in trigonometry. The strength of this strategy lies not only in its digital delivery but also in its pedagogical coherence. MoSIM integrates the 5E inquiry model with the principles of mobile seamless learning, creating a structured and flexible framework that supports sustained cognitive engagement across contexts (Juniantari et al., 2025; Safiah et al., 2020). Each phase of the 5E is systematically embedded into the media to guide students through progressive stages of inquiry. Through this iterative learning cycle, students gain multiple opportunities to build and refine their understanding, promoting deeper conceptual processing and retention (Schallert et al., 2022).

The MoSIM was guided by a theoretical framework that aligns the 5E inquiry model with ten dimensions of MSL. This alignment enables a learning experience that is not constrained by time, location, or device, allowing students to transition fluidly between formal classroom instruction and informal self-directed learning environments (Hendrowibowo & Kristanto, 2023; Moon et al., 2023; Wong & Looi, 2011). Such flexibility is essential for mastering complex mathematics topics like trigonometry, which require not only procedural practice but also sustained conceptual reflection and engagement with diverse forms of representation. For instance, students may begin exploring a concept in class and continue elaborating it through interactive simulations or visualizations at home, fostering a sense of continuity and deeper internalization.

The framework, as shown in Image 3, illustrates the theoretical foundation of the MoSIM strategy, which integrates the 5E activities with ten dimensions of MSL. Each inquiry stage —Engage, Explore, Explain, Elaborate, and Evaluate — is systematically aligned with relevant MSL dimensions and supported by specific learning activities conducted both in-class and out-of-class. During the Engage phase, students formulate inquiry questions by observing contextual problems presented through MoSIM on their mobile devices. In the Explore phase, they independently investigate trigonometric concepts using digital tools such as instructional videos, modules, and GeoGebra, based on their learning style. In the Explain phase, students can engage in discussions via the WhatsApp forum embedded in MoSIM, especially during out-of-class learning. The Elaborate phase is supported by MoSIM worksheets containing broader, inquiry-based problems that help students deepen their conceptual knowledge. Finally, the Evaluate phase is facilitated through a quiz available on MoSIM, which promotes reflection and self-assessment.

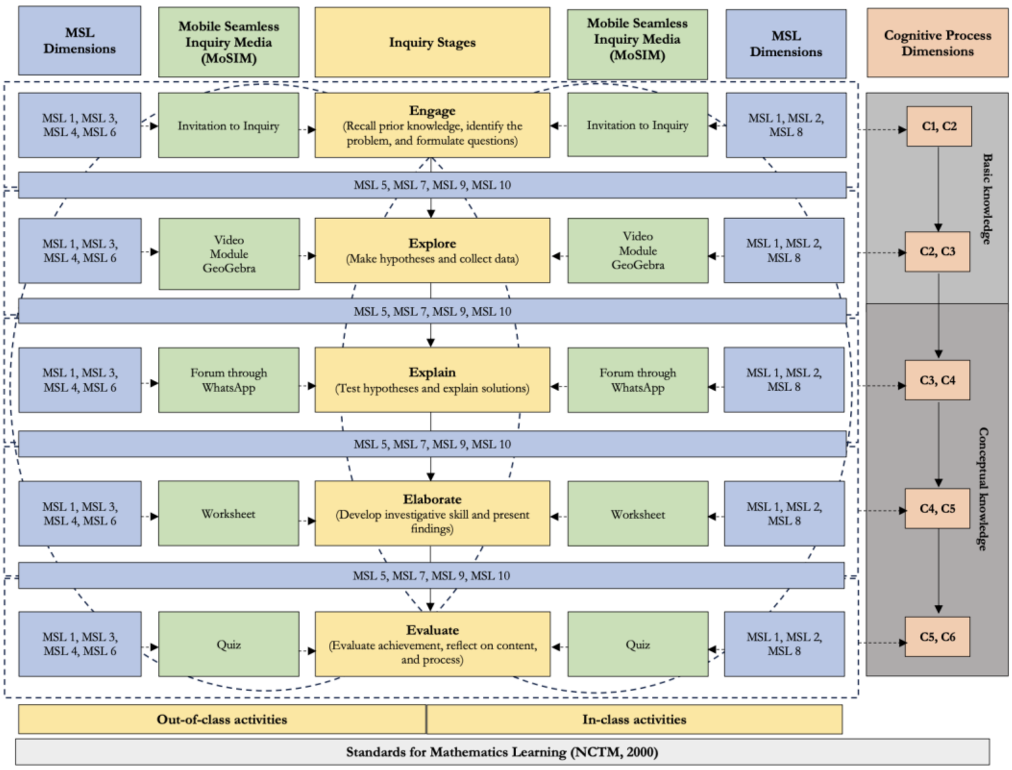

Image 3. MoSIM Theoretical Framework

Each phase in Image 3 is aligned with cognitive process dimensions ranging from C1 to C6, from basic knowledge to conceptual knowledge, fostering a systematic progression of conceptual knowledge. This alignment promotes deep learning by ensuring continuity of inquiry, encouraging metacognitive engagement, and allowing flexible pacing across both formal and informal learning environments.

To implement this framework effectively, the MoSIM was developed using the eXeLearning platform, a versatile authoring tool that enables the creation of interactive, web-based instructional media without requiring advanced programming skills (Silalahi, 2020). This platform made it possible to systematically align digital content with each phase of the 5E inquiry model, ensuring pedagogical coherence and accessibility. By offering multimodal access to content and supporting asynchronous exploration, MoSIM enabled students to revisit complex concepts at their own pace and in settings beyond the classroom. Such integration of flexible, learner-centered media significantly enhances interactivity and autonomy, two key elements for promoting conceptual learning in mathematics (Suryawan et al., 2023).

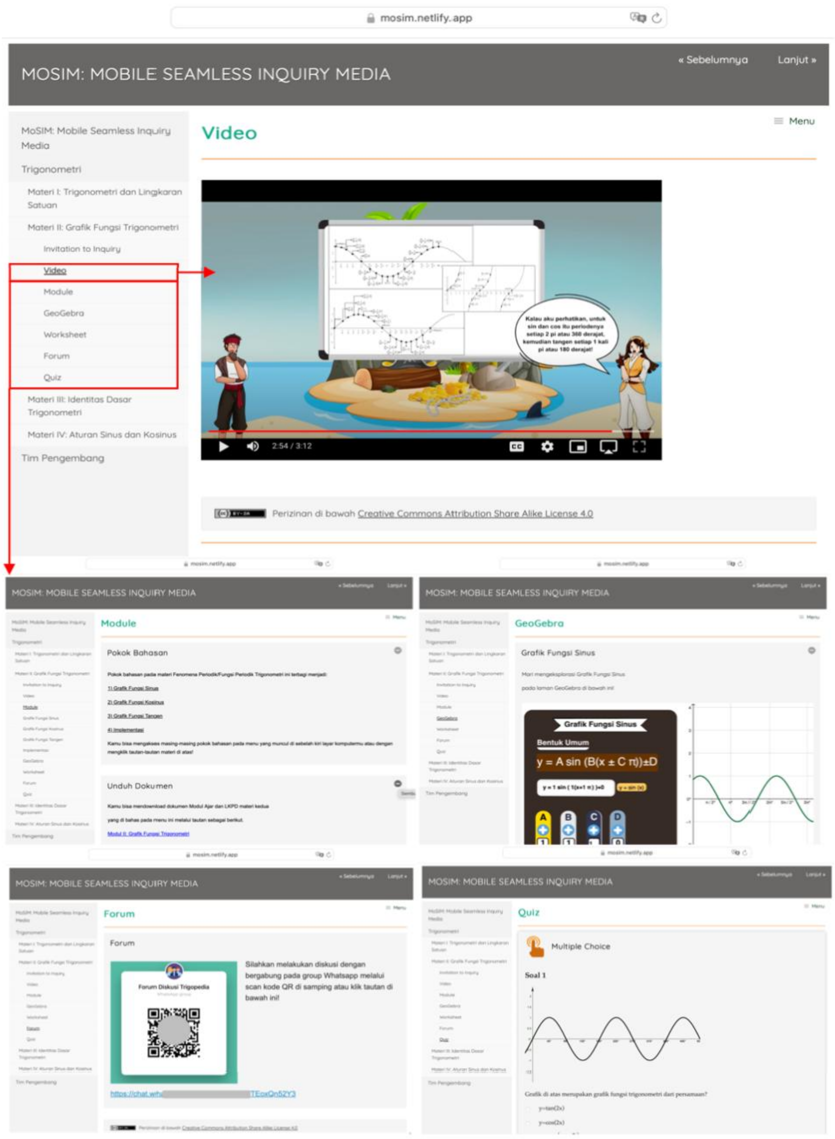

Image 4. Media Features in MoSIM

The components of MoSIM's media integration are illustrated in Image 4. This image details how the tools were mapped to each learning phase, offering students scaffolded opportunities to build conceptual knowledge and participate in collaborative and independent inquiry activities. The structure shown in Image 4 illustrates how MoSIM provides a coherent mapping between inquiry phases and media features that support each cognitive and metacognitive process. These tools not only align with the learning objectives but also enhance students' engagement and autonomy. By offering diverse and interactive resources, MoSIM ensures that learners can explore mathematical concepts in ways that suit their pace, context, and preferred modes of representation. This alignment between pedagogy, content, and technology is essential for strengthening conceptual learning outcomes in mathematics.

The effectiveness of MoSIM is further reinforced by its digital features, which are carefully aligned with both inquiry pedagogy and conceptual learning indicators. First, the interactive video modules used in the engage phase offer contextually rich, real-world problem scenarios that activate students' prior knowledge and stimulate intellectual curiosity. These videos are not merely passive content but are embedded with prompts that encourage prediction, questioning, and making connections, skills essential to initiating meaningful inquiry. By situating learning within familiar or relatable situations, these modules help bridge the gap between abstract trigonometric concepts and students' everyday experiences. This initial activation is critical, especially for learners who may otherwise find the topic too theoretical or disconnected from real-life applications (Hidayat et al., 2023; Sumandya et al., 2023).

Second, the GeoGebra included in the explore and elaborate phases serves as a powerful visual tool that allows students to interact with mathematical representations dynamically. Unlike static diagrams in textbooks, these applets respond in real time to user manipulation, enabling students to experiment with parameters and observe how changes affect graphical outcomes. This visual interactivity promotes spatial reasoning and helps students grasp complex ideas such as the relationship between angles and periodic behaviour in trigonometric functions. Moreover, it strengthens their ability to analyse conceptual relationships and translate between symbolic, graphical, and contextual forms, competencies central to conceptual learning outcomes (Bekene Bedada & Machaba, 2022; Hidayat et al., 2023; Zamorano Urrutia et al., 2019). In this way, MoSIM offers more than visualisation.

Third, the inclusion of digital worksheets and self-assessment tools enhances the explain and evaluate phases by fostering metacognitive awareness and independent learning. These components support students in organising their thoughts, checking their understanding, and receiving immediate feedback on their progress. Unlike traditional assignments, which often delay feedback, these digital tools allow timely self-correction, encouraging students to revise their reasoning and confront misconceptions. This iterative process strengthens retention and promotes conceptual depth, particularly for topics like trigonometric identities, which often require multiple representations and logical justification (Zamorano Urrutia et al., 2019). By integrating feedback into the learning cycle, MoSIM supports not only performance but also the development of students' self-regulated learning skills.

In contrast, the control group, although guided by the same 5E inquiry cycle, relied solely on printed worksheets and face-to-face teacher explanation. It limits the depth and flexibility of engagement. These paper-based instructional materials, while structured, lacked the multimodal features that support diverse learning preferences. Consequently, students in this group had fewer opportunities to explore representations interactively or revisit learning content outside of classroom hours. Previous research has shown that such conventional approaches, which often emphasise procedural accuracy over conceptual understanding, tend to result in fragmented and rigid knowledge structures that are less transferable to new problems (Cavey & Berenson, 2005; Nanmumpuni & Retnawati, 2021).

A key strength of MoSIM lies in its seamless learning design, which enables fluid transitions between learning environments, such as from school to home or from individual to collaborative tasks. The mobile-accessible format ensures that students can revisit content as needed, reinforcing learning over time and accommodating different learning paces. This extended engagement beyond class hours helps mitigate one of the common barriers in implementing inquiry-based learning and limited instructional time (Moon et al., 2023; Safiah et al., 2020; Wong & Looi, 2011). By distributing inquiry activities across time and space, MoSIM fosters learning continuity and allows for deeper, uninterrupted conceptual processing.

Moreover, the study's results resonate strongly with existing literature that emphasizes the importance of representational fluency in the learning of trigonometry. Prior research has consistently shown that students often struggle not due to a lack of motivation or effort, but because they encounter significant challenges in connecting and interpreting different forms of mathematical representation, particularly graphs, symbolic expressions, and real-world contexts (Hidayat et al., 2023; Kamber & Takaci, 2018). These difficulties hinder students' ability to form a coherent understanding of trigonometric concepts and to transfer knowledge across problems. The MoSIM strategy directly addresses these representational challenges by offering a diverse array of learning resources, including dynamic simulations, contextualized problem sets, and interactive visual models. These features are intentionally designed to encourage flexible thinking and support students in making meaningful connections between abstract and concrete representations. This alignment between instructional design and the cognitive demands of trigonometry provides a strong pedagogical foundation, which explains why MoSIM is particularly effective in supporting and improving students' conceptual learning outcomes.

On the other hand, this study was conducted within a single school context, involving students who shared relatively similar educational experiences and learning environments. The limited scope and short duration of the intervention pose constraints on the generalizability of the findings to broader populations. While the results suggest promising outcomes, they may not reflect the diverse challenges faced by schools with different socioeconomic, technological, or cultural conditions. Furthermore, the successful implementation of the MoSIM strategy relies on the availability of essential digital infrastructure, including mobile devices and reliable internet connectivity, resources that may not be uniformly accessible across schools or geographic regions (Moon et al., 2023). Another important but unexamined factor is teacher readiness; the effectiveness of MoSIM also depends on teachers' digital competence, pedagogical adaptability, and willingness to adopt technology-enhanced inquiry models. Since these variables were not addressed in the current study, future research should explore professional development frameworks that support MoSIM integration, assess its long-term effects on learning retention, and investigate its scalability across various mathematical domains and heterogeneous student populations.

Theoretically, the findings of this study contribute to the advancement of mobile seamless learning and inquiry-based learning through the implementation of the MoSIM strategy. The results support the theoretical proposition that seamless learning environments enhance students' conceptual learning outcomes by bridging formal and informal learning contexts. Practically, this study demonstrates how mobile technology can be effectively integrated into inquiry-based learning. This approach aligns with the demands of the digital era and provides a strategic framework for improving conceptual mathematics learning outcomes in secondary education.

Conclusion

This study demonstrates that the Mobile Seamless Inquiry Media (MoSIM) strategy significantly enhances students' conceptual mathematics learning outcomes when compared to conventional strategies. The one-way ANCOVA results revealed a statistically significant difference in posttest performance between the two groups after controlling for pretest scores ($F = 5.84$; $p = 0.01$), indicating that the instructional strategy had a meaningful impact on students' conceptual mathematics learning outcomes. Students who learned trigonometry through the MoSIM strategy achieved higher mean scores ($M = 80.03$; $SE = 1.03$) than those taught using conventional strategies ($M = 76.57$; $SE = 0.99$).

The effectiveness of MoSIM is rooted in its pedagogical design, which integrates the 5E learning cycle: engage, explore, explain, elaborate, and evaluate, within a mobile learning environment. This structure supports sustained inquiry by providing access to materials beyond the classroom, enabling students to engage in deeper learning processes through repeated exploration, reflection, and problem-solving. Unlike conventional strategies that rely on static worksheets and in-class instruction, MoSIM allows students to revisit complex concepts at their own pace using interactive tools such as simulations, video modules, and digital worksheets. These features not only promote greater conceptual clarity but also foster autonomy and engagement, making MoSIM a promising alternative for improving mathematics learning outcomes, particularly in challenging domains such as trigonometry.

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