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# Mobile seamless inquiry media: effective strategies for enhancing students' conceptual mathematics learning outcomes in the digital era

**M. Juniantari[1], I.N.S. Degeng[2], S. Ulfa[3]**
*Universitas Negeri Malang, Malang, Indonesia.*
*E-mail: [1]mdjuniantari@undiksha.ac.id; [2]nyoman.sudana.d.fip@um.ac.id; [3]saida.ulfa.fip@um.ac.id*

**A. Nakaya**
*Hiroshima University, Hiroshima, Japan.*
*E-mail: anakaya@hiroshima-u.ac.jp*

✉ *mdjuniantari@undiksha.ac.id*

***Abstract.*** *Introduction.* In the digital age, the implementation of innovative strategies and technology-based approaches that enhance conceptual understanding in mathematics education is becoming increasingly essential. By utilising mobile technology, mobile seamless inquiry media (MoSIM) enables students to engage in research activities anytime and anywhere, thereby overcoming the constraints of traditional classroom learning. *Aim.* This study *aims* to develop and evaluate tools for MoSIM. *Methodology and research methods.* The study was conducted using the ADDIE pedagogical design model. Data analysis included a paired *t*-test and growth calculation (N-gain) to evaluate improvements in conceptual learning outcomes. *Results and scientific novelty.* The results indicate that MoSIM significantly enhances students' conceptual understanding, showing a statistically significant difference (*Sig.* < 0.001) and an N-gain percentage of 72.42%. This research presents an innovative educational solution by integrating inquiry-based learning (IBL) and seamless learning in a mobile-based format, specifically designed to align with the learning preferences of Generation Z, who are proficient with technology. *Practical significance.* MoSIM provides a practical and flexible solution for teaching abstract mathematical concepts beyond classroom limitations. Its successful application highlights its potential to improve mathematics education and serve as a model for integrating mobile technology into other instructional contexts.

***Keywords:*** inquiry-based learning, seamless learning, mobile seamless inquiry media (MoSIM), conceptual learning outcomes, mathematics education, digital learning strategies, generation Z learners, instructional technology, ADDIE model

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# Мобильные средства «бесшовного» обучения исследовательской деятельности: эффективные стратегии для повышения результатов обучения концептуальной математике студентов в цифровую эпоху

**М. Джуниантари[1], И.Н.С. Дегенг[2], С. Улфа[3]**
*Государственный университет Маланга, Маланг, Индонезия.*
*E-mail: [1]mdjuniantari@undiksha.ac.id; [2]nyoman.sudana.d.fip@um.ac.id; [3]saida.ulfa.fip@um.ac.id*

**А. Накая**
*Университет Хиросимы, Хиросима, Япония.*
*E-mail: anakaya@hiroshima-u.ac.jp*

✉ *mdjuniantari@undiksha.ac.id*

***Аннотация.*** *Введение.* В цифровую эпоху критически важным становится использование инновационных стратегий и подходов, основанных на технологиях, способствующих улучшению концептуальных результатов обучения математике. Использование мобильных технологий, MoSIM позволяет студентам участвовать в исследовательских мероприятиях в любое время и в любом месте, преодолевая ограничения традиционного классного обучения. *Цель* настоящего исследования – разработка и оценка мобильных средств «бесшовного» обучения исследовательской деятельности (MoSIM). *Методология, методы и методики.* Исследование было проведено с использованием модели педагогического дизайна ADDIE. Анализ данных включал парный *t*-тест и расчет прироста (N-gain) для оценки улучшения концептуальных результатов обучения. *Результаты и научная новизна.* Результаты показывают, что MoSIM значительно улучшает концептуальное понимание студентов, что подтверждается статистически значимой разницей результатов (*Sig.* < 0.001) и процентом прироста (N-gain) 72,42 %. Это исследование представляет инновационное образовательное решение, объединяющее IBL и «бесшовное обучение» в мобильном формате, адаптированном к характеристикам поколения Z, которое обладает высокой цифровой грамотностью. *Практическая значимость.* MoSIM обеспечивает практичное и гибкое решение для преподавания абстрактных математических концепций за пределами ограничений классного времени. Его успешное применение служит моделью для интеграции мобильных технологий в другие учебные контексты.

***Ключевые слова:*** обучение на основе исследований, «бесшовное» обучение, мобильные средства «бесшовного» обучения исследовательской деятельности (MoSIM), концептуальные результаты обучения, математическое образование, цифровые стратегии обучения, обучающиеся поколения Z, образовательные технологии, модель ADDIE

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## Introduction

Mathematics plays a critical role in every sector of human life. Beyond its utility in analysing real-world situations, mathematics fosters the development of critical thinking and problem-solving skills [1, 2]. Conceptual knowledge, as emphasised by M. A. Al Mutawah, R. Thomas, A. Eid et al. [3] and J. Kilpatrick, J. Swafford [4], enables students to relate mathematical concepts to real-life contexts and holistically organise their understanding, underpins these abilities and better prepares them to apply mathematics across various aspects of life. The development of such conceptual knowledge relies on effective learning strategies.

According to the Principles and Standards for School Mathematics [5], the primary focus of mathematics learning should be conceptual understanding, which aligns with the nature of mathematics, which emphasises conceptual learning [3, 6]. Active engagement cultivates conceptual knowledge, empowering students to take charge of their learning progress. However, student learning outcomes in mathematics in Indonesia remain low, as evidenced by the country's average PISA mathematics score of 366 in 2022, below the international average of 472 [7, 8]. Despite the Indonesian government's target PISA score of 388 outlined in the 2020–2024 National Medium-Term Development Plan [9], this score represents a decline from 379 in 2018, suggesting that current mathematics teaching methods are insufficient to improve students' conceptual learning outcomes.

The abstract nature of mathematical concepts presents significant challenges for students [10, 11]. The limited time available for instruction further restricts the implementation of strategies that could improve students' conceptual learning outcomes [12]. As a result, many teachers continue to rely on direct instructional methods that fail to engage students actively [13], contributing to a limited understanding of mathematical concepts [14, 15, 16]. In the digital era, integrating mobile technologies into learning strategies provides a promising solution for increasing student engagement and enhancing conceptual understanding despite time constraints in the classroom. This study explores the effectiveness of mobile seamless inquiry media (MoSIM), a learning strategy that combines the strengths of inquiry-based learning (IBL) and seamless learning. We designed MoSIM to align with the characteristics of Generation Z students, who are already accustomed to using mobile technology in their daily lives. By implementing MoSIM, teachers can extend the teaching of abstract mathematical concepts beyond the limitations of classroom time.

IBL is an active learning approach that engages students directly in the process of discovery, helping them understand abstract mathematical concepts [17]. The research conducted by I. M. Gómez-Chacón, A. Bacelo, J. M. Marbán et al. [18] has demonstrated that this model positively influences students' attitudes towards mathematics. Through IBL, students learn in a manner similar to scientists: observing phenomena, posing questions, forming hypotheses, collecting data, identifying patterns, and making generalisations [17, 18]. This process-oriented model helps develop students' mathematical skills, knowledge, and dispositions, ultimately improving their conceptual, procedural, and metacognitive learning outcomes [19].

Given the constraints of limited class time, implementing effective IBL requires innovative strategies, particularly for complex subjects such as mathematics [20, 21]. In the digital era, the integration of mobile technology offers new opportunities; however, there is still a lack of practical strategies for educators to balance granting students' freedom with providing practical support through mobile technology [22]. Seamless learning offers a solution by extending IBL beyond the formal classroom setting, enabling students to engage in meaningful learning experiences across various contexts [23, 24]. This strategy transforms limited learning time into flexible, continuous learning opportunities [24, 25, 26]. In today's digital age, mobile technology plays a crucial role in supporting seamless learning, bridging the gap between classroom and out-of-classroom learning environments [26, 27]. As more and more students rely on digital devices, mobile technology has become an essential educational tool [28], which makes seamless learning not only possible but also necessary to meet the needs of modern learners [29].

Though introduced in the 1990s, seamless learning remains new and unfamiliar in many developing countries, including Indonesia [30]. There is still a lack of research on strategies that integrate IBL and seamless learning to improve students' conceptual mathematics learning outcomes. Previous studies have demonstrated that the application of IBL, both inside and outside the classroom (e.g. in a flipped classroom), effectively increases students' motivation and self-confidence, particularly in advanced topics like chemical reactions [31]. In higher education, IBL promotes collaboration and communication about new knowledge [21]. However, IBL's implementation at the K-12 level remains underexplored [21, 32]. The research conducted by D. N. Ariani, M. S. Sumantri and F. C. Wibowo [33] on Android-based module media to support IBL, both in and outside the classroom, has demonstrated improvements in students' mathematical problem-solving skills [33]. However, this research highlights the need to develop further IBL media that go beyond static modules and incorporate more dynamic and interactive learning activities. Therefore, this study aims to introduce an innovative solution by developing the Mobile Seamless Inquiry Media (MoSIM) to enhance students' conceptual mathematics learning outcomes.

This study seeks to answer the following research question:

1. How effective is MoSIM in enhancing students' conceptual mathematics learning outcomes?

## Literature Review

### *Conceptual Mathematics Learning Outcomes*

Conceptual knowledge, a type of knowledge within the cognitive domain, involves understanding categories, classifications, and the relationships between them, thus forming more complex and organised structures [34]. In mathematics, conceptual knowledge reflects an integrated and functional understanding of ideas that extends beyond isolated facts and methods [4, 35, 36]. As it enables students to connect the fundamental ideas underlying relevant mathematical concepts [2] and directly influences their learning outcomes in mathematics [37], this foundation is essential for developing other mathematical skills.

To enhance conceptual learning outcomes, teachers can prioritise developing students' conceptual knowledge by integrating diverse topics in the curriculum, fostering connections across different domains, and supporting reasoning and problem-solving fluency [38]. Three key indicators serve to measure these outcomes: 1) analysing relationships between concepts, 2) identifying examples and non-examples of concepts, and 3) expressing concepts in various representations [4]. These indicators emphasise understanding relationships, applying knowledge flexibly, and presenting ideas in multiple forms.

Conceptual knowledge grows through forming relationships between pieces of information, whether by connecting new and existing knowledge or recognising patterns across contexts [35, 36, 38]. As students build these connections, they advance from primary relationships directly tied to specific contexts to reflective relationships, where they identify underlying similarities across broader mathematical concepts. This process deepens understanding, supporting cognitive reorganisation essential for meaningful learning [39]. Such a relational approach aligns well with inquiry-based learning, where students actively explore, question, and reflect on their understanding, building and reorganising their knowledge in ways that reinforce conceptual mastery [21].

### *Inquiry-Based Learning*

Researchers increasingly recognise inquiry-based learning (IBL) as a practical approach to stimulating students' curiosity and motivation by connecting formal education with real-life phenomena [22, 40]. While IBL in mathematics may differ in context from science education, both approaches share a core goal: engaging students in the practices and behaviours of experts [17]. In IBL, teachers guide students through problems that encourage them to discover and apply concepts independently rather than directly providing facts or answers. Students engage in solving problems, making conjectures, experimenting, exploring, creating solutions, and communicating their findings, which fosters a deeper, more conceptual understanding and enhances critical thinking and problem-solving skills [21].

IBL transforms students from passive learners into active participants [40]. It redefines the role of the teacher as a facilitator who guides students, both individually and in groups, to solve problems with appropriate support [31]. The constructivist theories of John Dewey and Jerome Bruner, emphasising "learning by doing", serve as the foundation for inquiry-based learning (IBL), making it highly relevant for 21st-century, student-centered learning [41, 42]. Applying IBL to mathematics learning fosters deeper student engagement and promotes a view of mathematics as knowledge to construct and discover [18]. This active involvement in inquiry activities enhances students' attitudes and perceptions toward mathematics as a whole.

Inquiry-based learning (IBL) uses an information processing model that presents problems to motivate students to engage in problem-solving through "invitation to inquiry" activities [43]. Teachers design the stages of IBL in mathematics around this approach, which provides a framework to facilitate student learning. In this study, the stages of IBL in mathematics follow the 5E learning cycle (Engage, Explore, Explain, Elaborate, and Evaluate) [19, 20], as shown in Figure 1. Students engage actively at each stage of the 5E model. When faced with an investigative problem, students generate questions based on their observations, with teachers guiding them to develop inquiry questions systematically and form hypotheses. They then collect data, often represented by mathematical concepts derived from relevant resources, to test these hypotheses [20, 44]. Afterwards, students present their findings and apply their skills to increasingly complex problems, which deepen their conceptual understanding and improve mathematics learning outcomes [37]. In the final stage, they assess both their learning process and results.

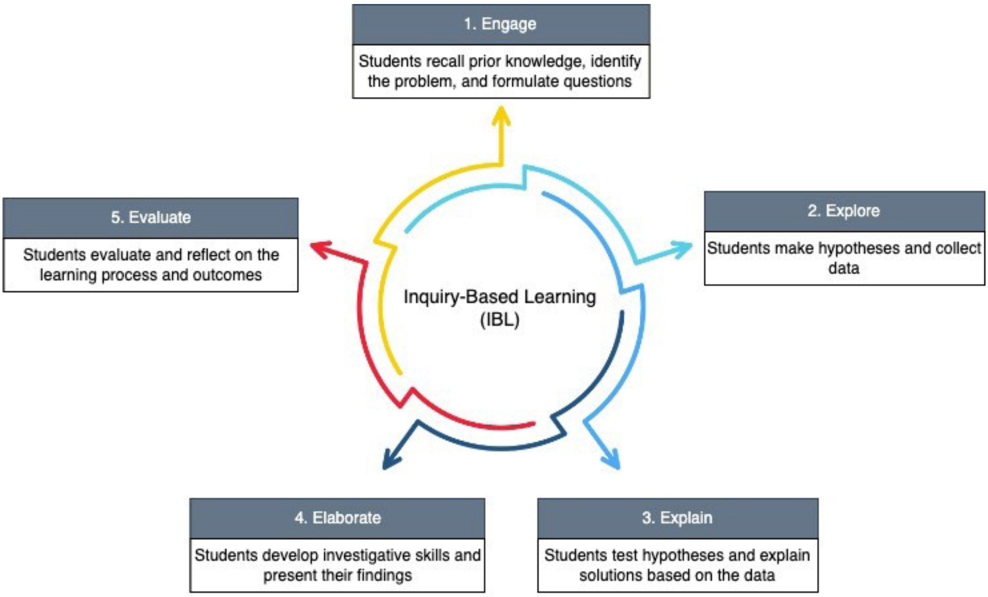


Fig. 1. Stages of inquiry-based learning

### *Seamless Learning*

The basic concept of seamless learning is that formal education alone cannot equip students with the skills and knowledge necessary for lifelong learning [24]. It emerged as a response to the limited time available in the classroom, particularly in the context of inquiry-based learning [23, 45, 46]. Inquiry learning often presents students with complex challenges, such as problem exploration, method design, experimentation, and data interpretation [29]. Due to time constraints in formal class settings, students are unable to complete these tasks fully. Seamless learning addresses this gap by providing opportunities for students to continue their learning beyond the classroom, extending the time for exploration and allowing them to deepen their understanding and skills.

Seamless learning bridges learning experiences across contexts, with mobile technology serving as an effective tool to facilitate context-sensitive learning [27]. This concept has significant potential for developing 21st-century skills by integrating formal and informal, individual and social, as well as physical and virtual learning environments [47]. This strategy enables students to learn anytime and anywhere using their devices [24, 25]. Thus, seamless learning allows teachers to transcend the traditional classroom-based learning concept.

The prospects of mobile-based learning include the use of mobile technology to create seamless and continuous learning spaces for students [48]. Seamless learning supported by mobile technology is known as Mobile Seamless Learning (MSL), which involves ten dimensions, as outlined in Table 1 [24]. These dimensions are a guide to creating a more holistic and immersive learning experience for students, particularly in the context of using mobile technology. Teachers can apply them in practice, with variations depending on the educational context, learning objectives, and available resources.

Table 1

Dimensions of mobile seamless learning

| MSL dimensions | Learning context |
|---|---|
| MSL 1 | Formal and informal learning, allowing structured class time to extend seamlessly into informal learning opportunities. |
| MSL 2 | Personal and social learning promotes a balance between individualised learning and social interaction, recognising both personal needs and the importance of collaborative exchange. |
| MSL 3 | Cross-time learning, emphasising continuous learning across different times, enables students to build on knowledge over various learning sessions. |
| MSL 4 | Cross-location learning, which allows students to engage with learning materials across various locations. |
| MSL 5 | Ubiquitous knowledge access enables students to access real-time information from relevant online sources during the learning process. |
| MSL 6 | Physical and digital worlds, by leveraging Wireless, Mobile, Ubiquitous, Technology-enhanced Education (WMUTE) technology, students can seamlessly transition between the physical and digital worlds, maintaining engagement and interaction in both environments. |
| MSL 7 | Combines various types of devices, allowing students to access the same learning materials through different devices, such as computers and mobile phones. |
| MSL 8 | Transitions between different learning tasks, such as data collection, brainstorming, and analysis. This flexibility supports inquiry-based learning, helping students develop 21st-century skills by smoothly moving through various stages of the learning process. |
| MSL 9 | Knowledge synthesis, where students combine old and new knowledge through mobile technology, enhances their ability to construct new understanding and promotes independent learning. |
| MSL 10 | Transitions between various stages of learning models, providing tools that help both students and teachers move smoothly through different pedagogical phases, enhancing flexibility in the learning process. |

## Methodology, Materials and Methods

### *Procedure for Developing MoSIM*

We use the ADDIE model (Analyse, Design, Develop, Implement, and Evaluate) to develop Mobile Seamless Inquiry Media (MoSIM) as a strategy to improve students' conceptual mathematics learning outcomes. We chose this model for its systematic and flexible nature, emphasising continuous evaluation, making it well-suited for creating educational products [49]. Figure 2 displays the ADDIE stages for developing MoSIM.

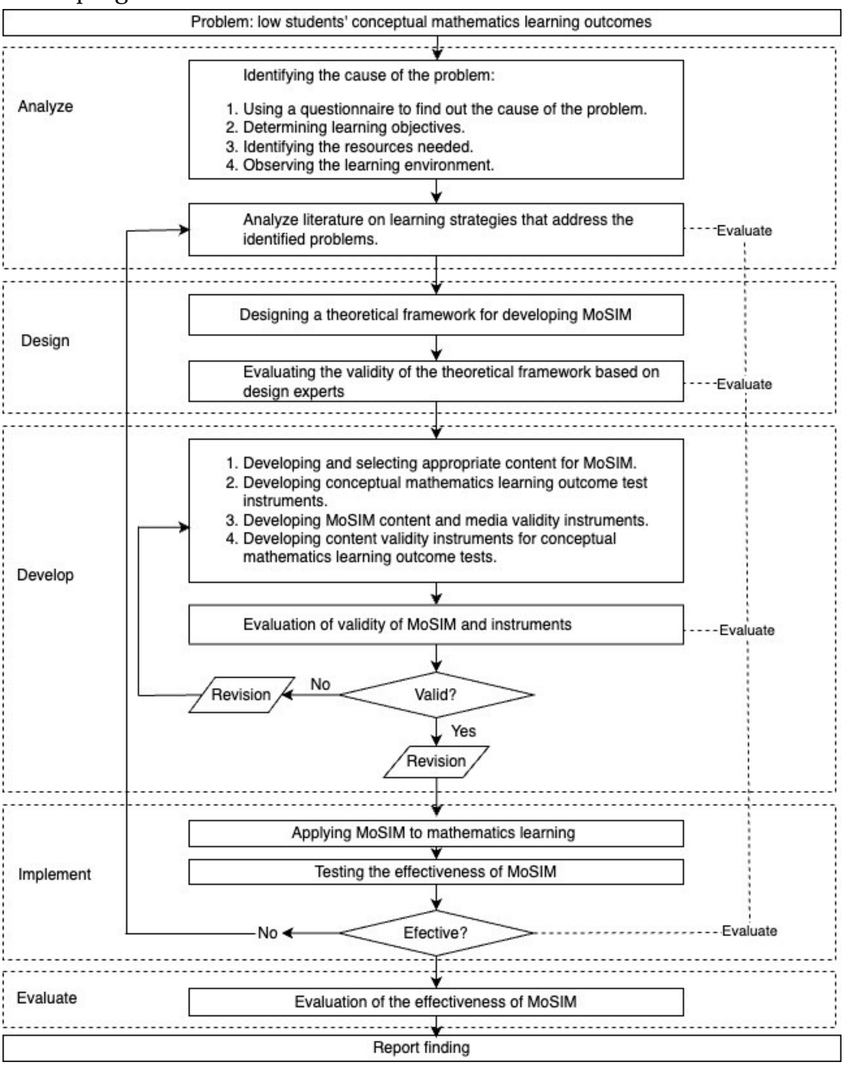


Fig. 2. ADDIE model procedure for developing MoSIM

### *Data Collection and Analysis Methods*

This study involved 35 eleventh-grade high school students as research subjects. During the analysis phase, we collected data on the factors contributing to students' low conceptual mathematics learning outcomes using the Mathematics Perception Questionnaire developed by I. M. Gómez-Chacón, A. Bacelo, J. M. Marbán et al. This questionnaire employs a five-point scale [18]. The questionnaire covered four indicators: mathematical ability, interest in mathematics, perception of the usefulness of mathematics, and mathematical self-concept, comprising a total of 32 statements. We compared the average mathematics perception scores of the students with the data presented in Table 2. We also conducted observations on the curriculum's learning objectives, learning resources, and the students' environment. We subsequently used these observational data as references for designing solutions.

Table 2

Conversion of average scores on five scales and categories [50]

| Scales | Categories |
|---|---|
| 4.21 < Mean ≤ 5.00 | Excellent |
| 3.40 < Mean ≤ 4.21 | Good |
| 2.60 < Mean ≤ 3.40 | Fair |
| 1.79 < Mean ≤ 2.60 | Poor |
| 1.00 < Mean ≤ 1.79 | Very poor |

A theoretical framework served as the foundation for designing the solution and developing MoSIM. Two design experts validated this framework using the instructional design internal validity questionnaire [51] on a five-point scale. The questionnaire included three indicators: theoretical foundation, strategy components, and strategy implementation, with a total of 15 statements. We then evaluated the validity of the theoretical framework based on the data in Table 2.

At the development stage, the validated theoretical framework serves as a reference for developing MoSIM. The development of MoSIM in this study is limited to Trigonometry material which is an important concept in mathematics, complex, contextual, and a prerequisite for understanding advanced mathematics [52, 53]. The scope of trigonometry material learned through MoSIM is presented in Table 3.

Table 3

Scope of trigonometry material in MoSIM

| Sub material | Conceptual learning objectives |
|---|---|
| Trigonometry and the Unit Circle | 1. Students can analyse the relationship between trigonometric function concepts using the unit circle.<br>2. Students can identify examples and non-examples of trigonometric function concepts.<br>3. Students can formulate trigonometric functions into various representations. |

| | |
|---|---|
| Trigonometric Function Graphs | 1. Students can analyse the relationship between concepts of trigonometric function graphs.<br>2. Students can identify examples and non-examples of trigonometric function graphs.<br>3. Students can formulate trigonometric functions into various representation based on the given trigonometric function graphs. |
| Trigonometric Function Identities | 1. Students can analyse the relationship between trigonometric function identity concepts.<br>2. Students can identify examples and non-examples of trigonometric function identities.<br>3. Students can formulate trigonometric function identities into various representations. |
| Sine and Cosine Rules | 1. Students can analyse the relationship between trigonometric concepts in the sine and cosine rules.<br>2. Students can identify examples and non-examples of problems that can be solved using the concept of the sine and cosine rules.<br>3. Students can formulate the sine rule into various representations. |

Based on the trigonometry learning objectives in Table 3, we selected appropriate platforms and content to support each stage of the inquiry process (engage, explore, explain, elaborate, and evaluate) in MoSIM. Two content experts and two media experts, respectively, assessed the validity of the MoSIM. We evaluated the level of validity of the content and media using the data presented in Table 2. In addition, we developed a test instrument to assess conceptual learning outcomes in mathematics. Two content experts assessed the validity of this instrument before testing the validity and reliability of the test items.

We then implemented MoSIM, which met the validity criteria, in mathematics learning. Students engaged with MoSIM both in-class and out-of-class. Each subtopic in trigonometry, as shown in Table 3, was learned during two class sessions. Out-of-class, students accessed MoSIM to independently build their conceptual knowledge. In class, each stage of the inquiry-based learning process was optimised through in-depth discussions to reinforce their conceptual knowledge.

To answer the research question, statistical analysis techniques, including paired sample t-test and N-gain percentage, were applied [54]. These techniques utilised the same group of students. The paired sample t-test was used to determine whether there was a significant difference in students' conceptual mathematics learning outcomes before and after using MoSIM, while the N-gain percentage was used to evaluate whether MoSIM effectively improved students' conceptual mathematics learning outcomes.

## Results

### *Findings*

A total of 35 students completed the mathematics perception scale questionnaire, which consisted of 32 statement items, online via the link https://bit.ly/skala-persepsi. Table 4 displays the average student perception of mathematics. According to Table 2, students generally have a positive perception of their interest, the usefulness of mathematics, and their mathematical self-concept. However, their confidence in their ability to understand mathematical concepts does not reflect this.

Table 4

Results of the mathematics perception scale questionnaire

| Aspect | Min | Max | Mean | Std. deviation | Category |
|---|---|---|---|---|---|
| Mathematical ability | 1 | 5 | 2.58 | 1.11 | Poor |
| Interest in mathematics | 1 | 5 | 3.47 | 1.07 | Good |
| Perceptions of the usefulness of mathematics | 2 | 5 | 4.20 | 0.71 | Good |
| Mathematical self-concept | 2 | 5 | 4.18 | 0.68 | Good |

Observation results on the objectives of mathematics learning show that conceptual learning outcomes are one of the main objectives in the *Kurikulum Merdeka*, which has been implemented in Indonesia since 2021. However, the available learning resources, such as teaching materials and text-based student worksheets, tend to focus on direct instruction activities or teacher-centered learning, so they do not support the achievement of curriculum objectives optimally. In addition, the time required to learn mathematics in class is minimal, as it is only 135 minutes per week. Despite adequate internet quality supporting the learning environment in schools in Singaraja, Bali, mobile technology has not fully utilised its potential for mathematics learning. So far, students have only used technology to deliver information on their routine tasks through applications like WhatsApp.

A positive perception of interest, usefulness, and self-concept in mathematics is essential for achieving strong conceptual learning outcomes in the subject. However, students' low perception of their mathematical abilities is primarily due to teaching methods that fail to engage them actively. The solution design addresses this issue by focusing on enhancing student engagement, integrating mobile technology, and bridging learning across various contexts, especially to overcome the limited classroom learning time.

The theoretical framework presents a solution design based on the IBL model, seamless learning strategies, constructivist learning theory, mathematics learning standards set by NCTM, and conceptual learning outcome indicators. Constructivist theory, which emphasises that learning is an active and constructive process based on students' experiences [55], aligns with the 5E stages in IBL, providing a structure for active, process-oriented mathematics learning [43]. Active mathematics learning is also a fundamental principle in global curriculum standards [56], which encourages the integration of subject-specific tools, such as GeoGebra, into the learning process. Seamless learning strategies act as catalysts, enabling learning to occur without time constraints and ensuring all components work collaboratively to achieve conceptual mathematics learning outcomes. This framework serves as a guide for designing MoSIM, a digital-based strategy aimed at addressing the low conceptual mathematics learning outcomes. Figure 3 illustrates how the MoSIM framework integrates inquiry activities across various learning contexts (mobile seamless learning, or MSL) to support all dimensions of cognitive learning outcomes, thereby effectively enhancing students' conceptual mathematics learning outcomes.

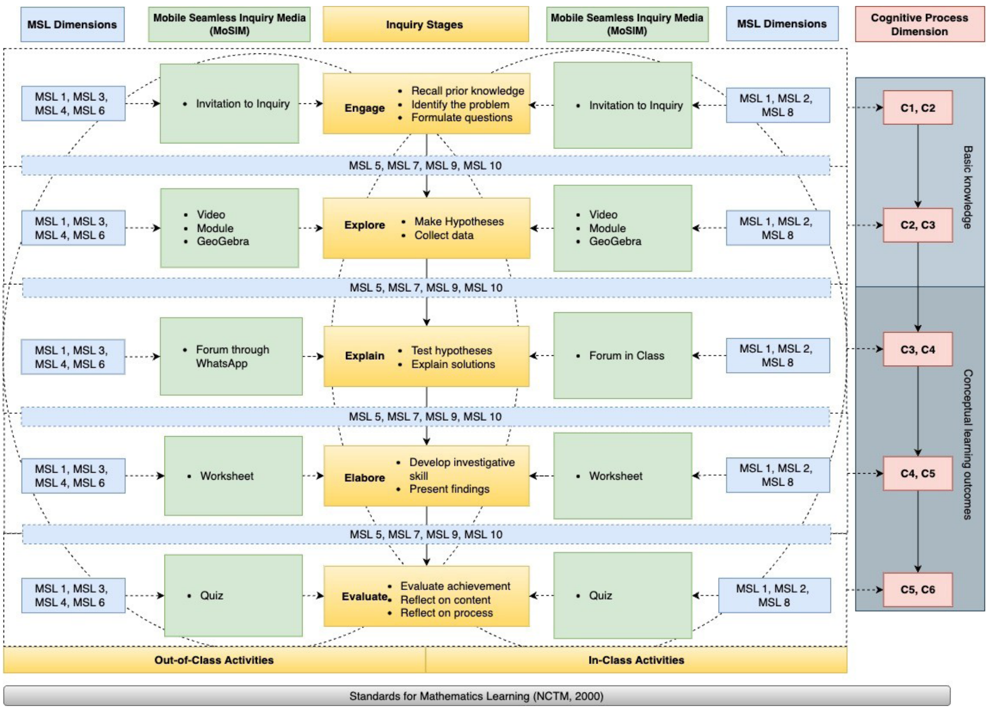


Fig. 3. Theoretical framework for developing MoSIM

Two design experts assessed the internal validity of this theoretical framework using an instructional design internal validity questionnaire. The questionnaire included three indicators: theoretical foundation, strategy components, and strategy application, comprising a total of 15 statements. Table 5 presents the assessment results. Table 2 classifies the theoretical framework for developing MoSIM as having excellent validity.

Table 5

Validity of the theoretical framework for developing MoSIM

| Aspect | Min | Max | Mean | Std. deviation | Category |
|---|---|---|---|---|---|
| Theoretical foundation | 4 | 5 | 4.60 | 0.52 | Excellent |
| Strategy components | 4 | 5 | 4.70 | 0.48 | Excellent |
| Strategy application | 4 | 5 | 4.70 | 0.48 | Excellent |
| Total mean | | | 4.67 | 0.49 | Excellent |

MoSIM was developed using the eXeLearning platform, which enables the creation of interactive digital media without requiring advanced programming skills [57]. Throughout the stages of MoSIM, the platform integrates videos, modules, worksheets, and GeoGebra. Designed for 11th-grade trigonometry, MoSIM can be accessed on personal devices through the link https://mosim.netlify.app/. Figure 4(a) presents the main menu, inviting students to engage with both contextual and non-contextual mathematical problems in the inquiry activity (Figure 4(b)). In the engagement phase, students observe the problems and receive scaffolding to help them formulate potential solutions. In the exploration phase, students explore mathematical concepts through the video menu (Figure 4(c)), module menu (Figure 4(d)), and GeoGebra (Figure 4(e)), catering to different learning styles. MoSIM integrates GeoGebra to provide dynamic visualisation of mathematical concepts. The Forum menu (Figure 4(f)) facilitates the explanation phase, where students discuss their findings using WhatsApp, a commonly used platform. In the elaboration phase, students develop inquiry skills in the worksheet menu (Figure 4(g)), tackling non-contextual problems to deepen their understanding of formal mathematics. Finally, the Quiz menu (Figure 4(h)) supports the evaluation phase, providing students with immediate feedback on their conceptual mathematics learning outcomes.

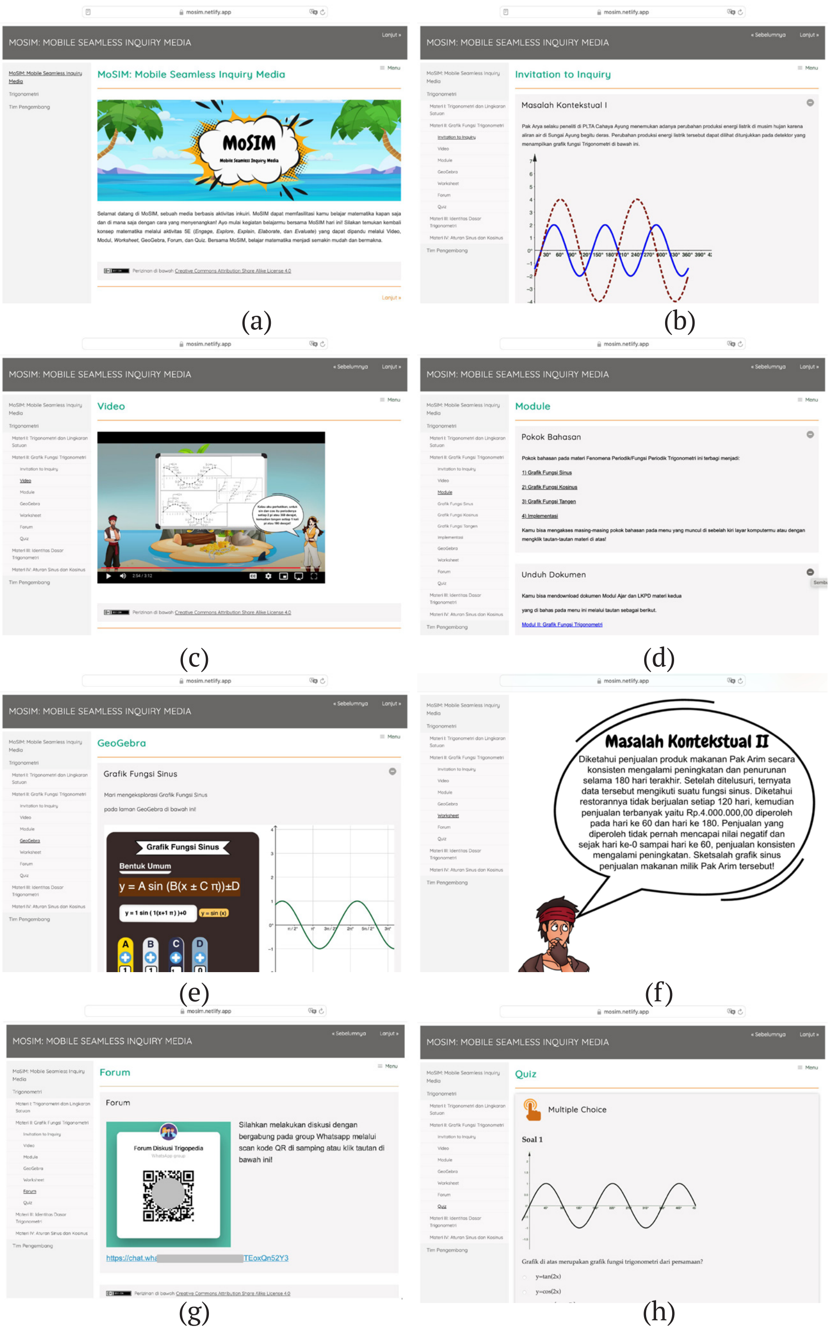


Fig. 4 (a-h). MoSIM features

During the development stage, we developed the test instrument to assess conceptual mathematics learning outcomes. We created a total of 36 multiple-choice questions, with 12 questions representing each conceptual learning outcome indicator. Based on evaluations by two content experts, the instrument received an excellent validity rating ($M = 4.77$). As shown in Table 6, item validity tests also revealed that 26 questions were valid and had high reliability, as shown by statistical analysis using *Cronbach's alpha split-half* model. We selected 21 out of the 26 valid questions, with seven questions representing each conceptual learning outcome indicator.

Table 6

The reliability of the conceptual mathematics learning outcome test

| | | | |
|---|---|---|---|
| *Cronbach's alpha* | Part 1 | Value | 0.73 |
| | | *N* of Items | 13 |
| | Part 2 | Value | 0.75 |
| | | *N* of Items | 13 |
| | | Total *N* of Items | 26 |

Two experts assessed the content and media validity of MoSIM for each aspect. To meet the research needs, we explicitly designed instruments to evaluate content and media validity. The content validity instrument included indicators of content relevance, clarity and presentation, and language use, comprising a total of 12 statements. Table 7 presents the results of the content validity assessment. Meanwhile, Table 8 presents the media validity instrument included indicators of visual design, technical functionality, user engagement, and navigation and usability, also comprising a total of 12 statements.

Table 7

Content validity of MoSIM

| Aspect | Min | Max | Mean | Std. deviation | Category |
|---|---|---|---|---|---|
| Content relevance | 4 | 5 | 4.88 | 0.35 | Excellent |
| Clarity and presentation | 4 | 5 | 4.38 | 0.52 | Excellent |
| Language use | 4 | 5 | 4.63 | 0.50 | Excellent |
| Total mean | | | 4.63 | 0.46 | Excellent |

Table 8 presents the results of the media validity assessment. Based on the comparison with the criteria in Table 2, MoSIM achieved an excellent level of validity according to the evaluations by content and media experts.

Table 8

Media validity of MoSIM

| Aspect | Min | Max | Mean | Std. deviation | Category |
|---|---|---|---|---|---|
| Visual design | 4 | 5 | 4.17 | 0.41 | Good |
| Technical functionality | 4 | 5 | 4.33 | 0.52 | Excellent |
| User engagement | 4 | 5 | 4.17 | 0.41 | Good |
| Navigation and usability | 4 | 5 | 4.67 | 0.52 | Excellent |
| Total mean | | | 4.33 | 0.46 | Excellent |

The trigonometry instruction used MoSIM, which meets the validity criteria. Students could access MoSIM outside the classroom through their mobile devices anytime and anywhere. We conducted the trigonometry instruction using MoSIM in the classroom over six sessions. We gave students a pre-test before the first session to measure their initial conceptual mathematics learning outcomes. We gave students a post-test after the sixth session. We analysed the effectiveness of MoSIM in improving conceptual mathematics learning outcomes using a paired sample *t*-test and N-Gain percentage. We checked the normality of the pre-test and post-test scores before conducting this test, and Table 9's results show that both scores have a normal distribution.

Table 9

Normality test for pre-test and post-test scores

| | ***Kolmogorov-Smirnov*** | | | ***Shapiro-Wilk*** | | |
|---|---|---|---|---|---|---|
| | **Statistic** | ***df*** | ***Sig*** | **Statistic** | ***df*** | ***Sig.*** |
| Pre-test | 0.14 | 35 | 0.70 | 0.98 | 35 | 0.60 |
| Post-test | 0.13 | 35 | 0.13 | 0.95 | 35 | 0.09 |

The results of the paired sample *t*-test in Table 10 show a significant difference between the pre-test and post-test scores.

Table 10

Paired sample *t*-test results

| | | **Paired differences** | | | | | ***t*** | ***df*** | ***Sig.* (Two-sided p)** |
|---|---|---|---|---|---|---|---|---|---|
| | | **Mean** | **Std. deviation** | **Std. error mean** | **95% confidence interval of the difference** | | | | |
| | | | | | **Lower** | **Upper** | | | |
| Pair 1 | Pre-test – Post-test | -43.40 | 13.94 | 2.36 | -48.19 | -38.61 | -18.41 | 34 | < 0.001 |

In contrast, the *N*-gain percentage results in Table 11 indicate that MoSIM has a high effectiveness in improving students' conceptual mathematics learning outcomes.

Table 11

*N*-gain percentage test results

| | ***N*** | **Min** | **Max** | ***Mean*** | **Std. deviation** |
|---|---|---|---|---|---|
| *N*-gain | 35 | 0.40 | 1.00 | 0.72 | 0.18 |
| *N*-gain percentage | 35 | 40.00 | 100.00 | 72.42 | 18.03 |
| Valid *N* (listwise) | 35 | | | | |

The results of the paired sample t-test in Table 10 and the *N*-gain percentage in Table 11 showed that MoSIM effectively enhances students' conceptual mathematics learning outcomes. Based on these results, further analysis was conducted on students' responses after learning trigonometry using MoSIM. Students' feedback was categorised into four main indicators: usability, engagement, interaction, and learning effectiveness, comprising a total of 12 statements. The results of these responses are summarised in Table 12.

Table 12

Student responses on the effectiveness MoSIM

| Aspect | Min | Max | Mean | Std. deviation | Category |
|---|---|---|---|---|---|
| Usability | 4 | 5 | 4.30 | 0.46 | Excellent |
| Engagement | 3 | 5 | 4.47 | 0.59 | Excellent |
| Interaction | 3 | 5 | 4.13 | 0.50 | Good |
| Learning effectiveness | 3 | 5 | 4.46 | 0.62 | Excellent |
| Total mean | | | 4.35 | 0.57 | Excellent |

Compared with Table 2, students' responses after learning trigonometry with MoSIM fall into the excellent category, indicating that MoSIM provided support for learning trigonometry concepts. The most popular resource is the GeoGebra simulation feature, which allowed students to explore trigonometric concepts such as the unit circle, the relationship between sine and cosine functions, and the graph patterns of trigonometric functions. However, the interaction aspect, with an average score of 4.13, falls into the good category. Although MoSIM is supported by a forum feature via WhatsApp, there is still potential to improve student interaction with the platform, further enhancing the collaborative learning experience.

## Discussion

There was a big difference between the student's scores on the pretest and posttest (*Sig.* < 0.001), and the average *N*-Gain percentage was 72.42%, showing that mobile seamless inquiry media (MoSIM) improves students' conceptual mathematics learning outcomes. These findings align with the principle proposed by M. A. Al Mutawah, R. Thomas, A. Eid et al. [3], as well as J. Kilpatrick and J. Swafford [4], which posits that concept-based learning is a vital component in fostering students' critical thinking and problem-solving skills. By providing students with the flexibility to learn anytime and anywhere, MoSIM offers an innovative approach that meets the learning needs of the digital era. The effectiveness of MoSIM also reflects efforts to address the low average PISA mathematics scores in Indonesia [7, 8] while supporting the educational quality improvement targets outlined in the National Medium-Term Development Plan [9].

The integration of IBL principles with seamless learning is the key to MoSIM's success. The IBL model allows students to actively engage in the learning process, from observation to the formulation of generalisations of mathematical concepts [17]. These inquiry-based activities strengthen students' understanding of abstract concepts in a more contextual and meaningful way [40, 44]. However, limited classroom time often poses a barrier to the full implementation of IBL [12]. To overcome this, MoSIM leverages mobile technology to extend learning beyond the classroom, connecting formal learning with informal activities in a flexible manner [24]. By utilising seamless learning, students can access and apply mathematical concepts in various situations, increasing their engagement while deepening their conceptual understanding.

Furthermore, Generation Z, with its high digital literacy, is the target audience for MoSIM's design. This media not only facilitates broader access to learning but also enhances student engagement through an interactive interface and dynamic learning activities [29]. This study confirms, as highlighted by R. Ramadhani, R. Umam, A. Abdurrahman et al., that technology-based learning strategies like MoSIM are effective in addressing the challenges of abstract mathematics learning [10]. Additionally, these findings have broader implications for digital-era learning strategies, particularly within the context of education in Indonesia. Future research could explore the application of MoSIM in other subjects or test its effectiveness on a larger scale to maximise the potential of mobile technology in education.

## Conclusion

Mobile Seamless Inquiry Media (MoSIM) is effective in enhancing students' conceptual mathematics learning outcomes, as evidenced by paired sample t-test analysis, with a significance value of *Sig.* $< 0.001$ in comparing pre-test and post-test scores from 35 research subjects and an N-Gain percentage of 72.42%. During the pedagogical experiment, students engaged with MoSIM features such as videos, modules, GeoGebra simulations, forums, and quizzes to explore trigonometry concepts, including the unit circle, trigonometric function graphs, trigonometric function identities, and the sine and cosine rules. These features significantly contributed to their understanding of fundamental trigonometric concepts by enabling them to analyse relationships between concepts, identify examples and non-examples of concepts, and express concepts in various representations.

MoSIM integrates the principles of Inquiry-Based Learning (IBL) and seamless learning, allowing students to engage in learning anytime and anywhere. This approach aligns with the characteristics of Generation Z, who possess high digital skills and actively engage with learning content. However, there is potential to further enhance collaborative learning opportunities within MoSIM to encourage more interaction among students.

## Limitations and Future Research

This study focused on the development and implementation of MoSIM for trigonometry learning in the mathematics curriculum for senior high school students in Indonesia. Further development and analysis of MoSIM on other mathematics content should be conducted. Future studies should explore how the specific characteristics of different mathematics content may require the adjustment of MoSIM features to optimise students' conceptual mathematics learning outcomes.

In addition, in this study, the effectiveness of MoSIM was tested on the same group of students, involving statistical techniques of paired sample t-test and N-Gain percentage. This limits the ability to generalise the findings to other student populations or to compare the effectiveness of MoSIM with other learning media.

Future studies should also focus on addressing several challenges related to technological infrastructure, educator training, and students' readiness to utilise digital learning media. It is important to explore how students' and teachers' readiness to use digital platforms affects the overall success of technology-based learning.

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***Information about the authors:***

**Made Juniantari** – Doctoral Student, Educational Technology Department, Universitas Negeri Malang, Malang, Indonesia; ORCID 0000-0003-3128-837X. E-mail: mdjuniantari@undiksha.ac.id

**I Nyoman Sudana Degeng** – Professor, Educational Technology Department, Universitas Negeri Malang, Malang, Indonesia; ORCID 0000-0003-4684-552X. E-mail: nyoman.sudana.d.fip@um.ac.id

**Saida Ulfa** – Professor, Educational Technology Department, Universitas Negeri Malang, Malang, Indonesia; ORCID 0000-0002-2302-7172. E-mail: saida.ulfa.fip@um.ac.id

**Ayami Nakaya** – Professor, Graduate School of Humanities and Social Sciences, Hiroshima University, Hiroshima, Japan; ORCID 0000-0002-7855-464X. E-mail: anakaya@hiroshima-u.ac.jp

***Contribution of the authors:***
M. Juniantari – research conceptualisation, editing.
I.N.S. Degeng – formal analysis and investigation, validation of methodology including learning model based on technology.
S. Ulfa – formal analysis and investigation, validation of methodology including learning media based on technology.
A. Nakaya – formal analysis and investigation, validation of methodology including curriculum.

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The authors have read and approved the final manuscript.

***Информация об авторах:***
**Джуниантари Маде** – докторант кафедры образовательных технологий Государственного университета Маланга, Маланг, Индонезия; ORCID 0000-0003-3128-837X. E-mail: mdjuniantari@undiksha.ac.id
**Дегенг И Ньоман Судана** – профессор кафедры образовательных технологий Государственного университета Маланга, Маланг, Индонезия; ORCID 0000-0003-4684-552X. E-mail: nyoman.sudana.d.fip@um.ac.id
**Улфа Саида** – профессор кафедры образовательных технологий Государственного университета Маланга, Маланг, Индонезия; ORCID 0000-0002-2302-7172. E-mail: saida.ulfa.fip@um.ac.id
**Накая Аями** – профессор Высшей школы гуманитарных и социальных наук Университета Хиросимы, Хиросима, Япония; ORCID 0000-0002-7855-464X. E-mail: anakaya@hiroshima-u.ac.jp

***Вклад соавторов:***
М. Джуниантари – концептуализация исследования, редактирование.
И.Н.С. Дегенг – формальный анализ и исследование, валидация методологии, включая модели обучения на основе технологий.
С. Улфа – формальный анализ и исследование, валидация методологии, включая средства обучения на основе технологий.
А. Накая – формальный анализ и исследование, валидация методологии, включая учебные программы.

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