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Realistic Mathematics Education Based Mobile Learning Media: Validity, Practicality, and Effectiveness in Teaching Compound Probability at Vocational High Schools

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Abstract

Background: The teaching of compound probability in vocational high schools continues to face challenges due to the abstract nature of the concepts and the limited integration of mathematical content with students' real-life experiences. These conditions often hinder students' conceptual understanding and learning engagement. Therefore, innovative instructional media that combine technological advancement with contextual learning approaches are needed.
Aims: This study aimed to develop a mobile learning application based on the Realistic Mathematics Education (RME) approach for teaching compound probability and to evaluate its validity, practicality, and effectiveness.
Methods: This research employed a research and development (R&D) design using the ADDIE model, which consists of analysis, design, development, implementation, and evaluation stages. The participants included 35 eleventh-grade students from a vocational high school in Malang, Indonesia. Data were collected through validation sheets, student and teacher response questionnaires, and learning achievement tests. The developed application was validated by a mathematics education lecturer and a mathematics teacher.
Results: The findings indicated that the developed mobile learning application achieved a high level of validity, with an average score of 86.37%. The practicality assessment showed positive responses from both students (84.09%) and the teacher (85.71%). Furthermore, the effectiveness test revealed that 85.71% of students achieved the minimum learning mastery criterion, with an average achievement score of 86.49.
Conclusion: The RME-based mobile learning application was found to be valid, practical, and effective for teaching compound probability in vocational high schools. By integrating contextual problems, interactive multimedia, and flexible learning opportunities, the application has the potential to enhance students' mathematical understanding and support innovative mathematics instruction in the digital era.

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INTRODUCTION

Recent scholarship has increasingly examined the pedagogical potential of mobile learning in mathematics education. Studies conducted in different educational contexts have demonstrated that mobile technologies enhance student as' engagement, self-regulated learning, and academic performance by providing flexible access to multimedia resources and interactive learning activities (Memon et al., 2022; Palalas & Wark, 2020). Within mathematics education, Android-based applications have been shown to improve conceptual understanding and support collaborative learning through simulations, quizzes, and visual representations (Jelatu et al., 2019; Khairunnisa & Suryaningsih, 2025). Parallel to these technological developments, researchers have consistently reported the effectiveness of Realistic Mathematics Education (RME) in fostering mathematical communication, literacy, and problem-solving abilities by connecting mathematical concepts to

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authentic contexts (A'la et al., 2025; Anugraheni et al., 2025). More recent studies have emphasized that contextualized mathematics instruction contributes not only to cognitive achievement but also to students' motivation and classroom participation (Clarke & Roche, 2018; Wang et al., 2017). Furthermore, the growing integration of digital media into mathematics classrooms has encouraged researchers to explore various instructional platforms, including mobile applications developed through Smart Apps Creator and other multimedia authoring tools (Engelbrecht & Borba, 2024; Soboleva et al., 2020). International evidence also suggests that technology-supported learning environments are most effective when they are grounded in robust pedagogical frameworks rather than focusing solely on technical features (Ahmed & Opoku, 2022; Major et al., 2021). Collectively, these findings indicate that both mobile learning and RME possess considerable potential for improving mathematics instruction. However, the relationship between these two approaches remains insufficiently explored.

Despite the substantial body of research on mobile learning and RME, at least four important limitations can be identified. First, previous studies have predominantly investigated mobile learning from a technological perspective by emphasizing usability, students' perceptions, and learning outcomes, while paying limited attention to the cognitive mechanisms through which digital media facilitate mathematical meaning-making (Abrahamson et al., 2020; Nguyen & Chen, 2026). Second, although RME has been widely recognized as an effective pedagogical approach, most empirical studies have implemented it in conventional classroom settings and printed learning materials, leaving its integration into mobile environments relatively underdeveloped (Kumar et al., 2024; Schorr et al., 2024). Third, existing research has largely concentrated on mathematical topics such as algebra, geometry, and mathematical literacy, whereas compound probabilityan inherently abstract topic that requires students to reason about multiple interconnected events has received considerably less attention. Fourth, empirical evidence concerning vocational high school students remains limited, even though this group exhibits distinctive learning characteristics and strong preferences for contextual and practice-oriented instruction. Consequently, current literature provides insufficient explanations regarding how mobile learning grounded in RME principles supports students' transition from contextual reasoning to formal mathematical concepts.

The research gap becomes even more evident when viewed from a theoretical perspective. Existing studies have generally treated mobile learning and RME as separate domains, resulting in a lack of conceptual models explaining how mobile technologies may strengthen the core principles of realistic mathematics education. In particular, little attention has been given to the role of multimedia features, interactive simulations, and immediate feedback in facilitating horizontal and vertical mathematization processes. From the perspective of RME, contextual problems, self-developed models, and guided reinvention are essential components for helping students construct mathematical knowledge (Son, 2022; Yilmaz, 2020). Meanwhile, mobile learning environments provide affordances that enable students to visualize probabilistic events, manipulate representations, and receive instant feedback on their reasoning. Theoretically, integrating these affordances with RME principles may offer a more comprehensive explanation of how students develop conceptual understanding in digital environments. Nevertheless, empirical studies examining this pedagogical integration remain scarce, particularly in the context of vocational mathematics education. Therefore, a critical gap persists between technological innovation and pedagogical theory in contemporary mathematics learning research.

Addressing this gap, the present study aims to develop a mobile learning medium based on Realistic Mathematics Education for teaching compound probability in vocational high schools and to evaluate its validity, practicality, and effectiveness. Beyond producing an instructional product, this study contributes to the theoretical development of mathematics education by extending the application of RME into mobile learning environments and by proposing an integrated framework that links contextual learning, multimedia interaction, and progressive mathematization. The study also contributes empirically by providing evidence regarding the ways in which mobile technologies can support students' conceptual understanding of compound probability through authentic problem-solving activities. From a practical perspective, the findings are expected to provide mathematics teachers with an innovative instructional alternative that is adaptable to contemporary educational needs and compatible with students' digital learning habits. Furthermore, the design principles generated through this research may serve as a reference for future studies seeking to integrate pedagogical theories with emerging educational technologies. Ultimately, this research seeks to bridge the divide between technological advancement and pedagogical effectiveness, thereby contributing to broader efforts to improve the quality of mathematics education in vocational settings.

METHOD

Research Design

This study employed a research and development (R&D) approach using the ADDIE instructional design model, which consists of five sequential phases: analysis, design, development, implementation, and evaluation (Mudjisusatyo et al., 2024; Wahira et al., 2023). The R&D approach was selected because the study aimed not only to produce an Android-based mobile learning application grounded in the principles of Realistic Mathematics Education (RME), but also to evaluate its quality in terms of validity, practicality, and effectiveness. The ADDIE framework was adopted because it provides a systematic and iterative procedure for integrating pedagogical content, technological features, and instructional objectives into a coherent learning environment. In addition, the model facilitates continuous product refinement based on empirical evidence collected throughout the development process. Therefore, the use of ADDIE was considered appropriate for developing an instructional medium intended to improve students' understanding of compound probability concepts in vocational education.

Research Setting and Ethical Considerations

The study was conducted at a public vocational high school in Malang, East Java, Indonesia, during the first semester of the 2025/2026 academic year, from July to August 2025. The school was selected because it had implemented the Merdeka Curriculum and possessed adequate technological infrastructure, including internet connectivity and widespread ownership of Android smartphones among students. Prior to data collection, official permission was obtained from the school administration and mathematics teachers. Participation in the study was voluntary, and all students were informed about the objectives and procedures of the research. To protect participants' privacy, all collected data were anonymized and used exclusively for academic purposes.

Participants and Sampling Procedure

The population comprised all eleventh-grade students enrolled in the vocational high school during the 2025/2026 academic year. A total of 35 students participated in the field-testing phase and were selected through purposive sampling. The inclusion criteria required participants to be officially registered in Grade XI, have completed prerequisite topics in probability, own Android-based smartphones compatible with the application, and attend all instructional sessions. Students who lacked compatible devices or did not complete the research activities were excluded from the analysis. In addition to student participants, two validators one university lecturer specializing in mathematics education and one experienced mathematics teacher were involved in assessing the quality of the developed product. Their involvement ensured that the application met pedagogical, content, and technological standards.

Research Instruments

Four instruments were employed to collect data: expert validation sheets, student response questionnaires, teacher response questionnaires, and achievement tests. The validation sheets assessed six dimensions of product quality, namely content accuracy, alignment with RME principles, instructional design, language appropriateness, visual presentation, and technical functionality. The practicality questionnaires measured usability, ease of navigation, accessibility, attractiveness, and perceived usefulness from both students' and teachers' perspectives. The effectiveness of the mobile learning application was evaluated using an achievement test consisting of multiple choice and problem solving items related to mutually exclusive events, non-mutually exclusive events, independent events, and conditional probability. The instruments were developed based on previous studies on mobile learning, instructional media evaluation, and mathematics education.

Instrument Validity and Reliability

Content validity was established through expert judgment involving the mathematics education lecturer and the mathematics teacher. The validators evaluated each instrument item in terms of relevance, representativeness, clarity, and alignment with the research objectives. Suggestions provided by the validators were incorporated into several rounds of revision before implementation. Instrument validity was quantified using percentage scores with validity categories defined as follows: 85–100% (very valid), 70–84% (valid), 50–69% (less valid), and below 50% (invalid). To assess reliability, the practicality questionnaires were piloted on students outside the research sample, and internal consistency was examined using Cronbach's alpha coefficient. Instruments were considered reliable when the alpha value exceeded 0.70. The achievement test was further reviewed to ensure consistency between learning objectives, indicators, and assessment items.

Research Procedure

The research followed the five phases of the ADDIE model. During the analysis phase, classroom observations, interviews with teachers, and curriculum reviews were conducted to identify instructional problems, student characteristics, technological readiness, and learning difficulties related to compound probability. The design phase involved preparing learning scenarios, storyboards, instructional materials, multimedia resources, and research instruments. In the development phase, the mobile learning application was created using Smart Apps Creator 3 by integrating videos, images, animations, contextual problems, interactive exercises, educational games, and assessment features. Subsequently, the product underwent expert validation and revision. The implementation phase consisted of classroom trials involving 35 students across three instructional sessions. Students installed and used the application individually and collaboratively while engaging with contextual activities designed according to RME principles. Finally, the evaluation phase focused on analyzing validity, practicality, and effectiveness data to determine the quality of the developed learning media.

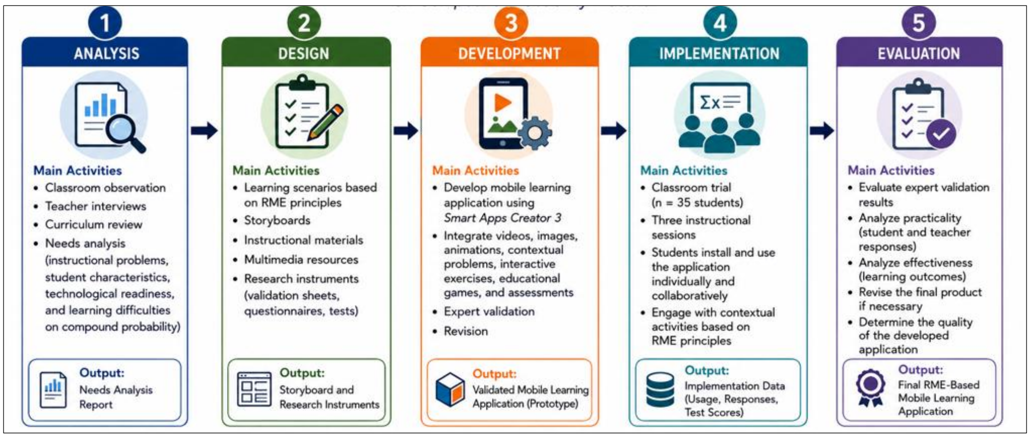


Figure 1. Research Procedure Based on the ADDIE Model

Data Analysis

Both qualitative and quantitative data analysis techniques were employed. Qualitative data, including comments and recommendations from validators, teachers, and students, were analyzed descriptively to support product revision. Quantitative data consisted of validation scores, questionnaire responses, pre-test scores, and post-test scores. Descriptive statistics, including means, percentages, and standard deviations, were calculated using IBM SPSS Statistics version 27. The validity and practicality of the mobile learning application were determined by comparing empirical scores with maximum possible scores and interpreting them according to predetermined criteria. To examine learning effectiveness, students' achievement before and after the intervention was compared using a paired-samples t-test after the normality assumption had been verified through the Shapiro–Wilk test. Statistical significance was established at the 0.05 level. Furthermore, the magnitude of learning improvement was assessed using Hake's normalized gain (g) and Cohen's d effect size. The normalized gain values were interpreted as low ($g < 0.30$), moderate ($0.30 \leq g < 0.70$), and high ($g \geq 0.70$), whereas Cohen's d values of 0.20, 0.50, and 0.80 indicated small, medium, and large effects, respectively. The developed media was considered effective when at least 85% of students achieved the Minimum Learning Competency Criteria and the intervention demonstrated statistically significant learning gains.

RESULTS AND DISCUSSION

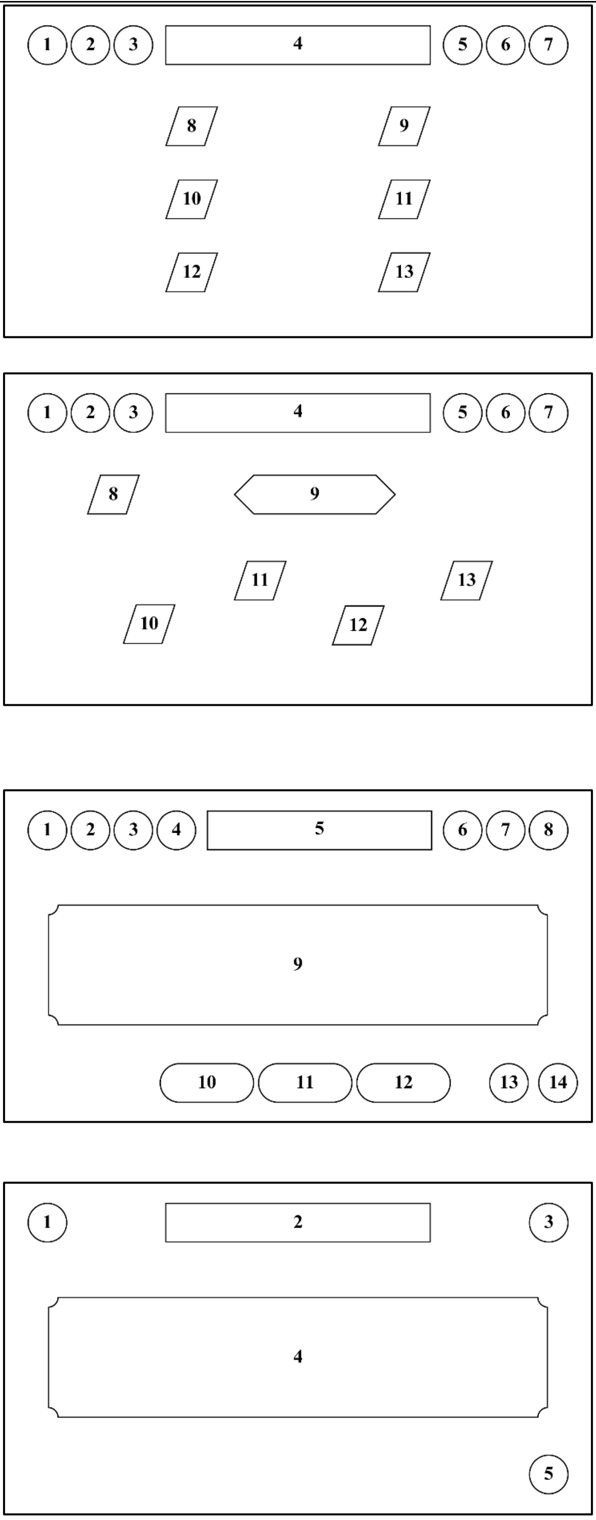
RESULTS

Product Development

The final product of this study was an Android-based mobile learning application developed using Smart Apps Creator 3 and designed according to the principles of Realistic Mathematics Education (RME) for teaching compound probability in vocational high schools. The development process followed the five stages of the ADDIE model, namely analysis, design, development, implementation, and evaluation. During the analysis stage, classroom observations, teacher interviews, and curriculum reviews were conducted to identify students' learning needs, conceptual difficulties, and technological readiness. The findings revealed that students experienced considerable challenges in understanding abstract probability concepts and relating them to real-life situations. These findings served as the foundation for designing a mobile learning environment that emphasizes contextual understanding, student engagement, and meaningful learning experiences.

The application integrated a variety of multimedia components, including instructional videos, audio recordings, images, animations, educational games, discussion forums, and assessment features. The learning materials covered major topics in compound probability, including mutually exclusive events, non-mutually exclusive events, independent events, and conditional probability. Guided by the principles of RME, the instructional content was structured progressively, beginning with contextual problems that reflected students' everyday experiences and gradually leading them toward formal mathematical representations. To support this process, the application encouraged students to engage in exploration, interpretation, problem solving, and reflection activities, thereby facilitating the transition from informal reasoning to mathematical abstraction.

The structure of the application consisted of several main menus, namely competencies, learning materials, videos, discussions, games, and evaluation. Interactive activities embedded within the application included connect the dots tasks, short answer exercises, multiple choice questions, drag and drop activities, and crossword puzzles. The storyboard developed during the design stage served as a blueprint for organizing the navigation system, learning sequence, and multimedia elements integrated into the application. Based on this design framework, the mobile learning application was transformed into a functional learning medium that supports independent and collaborative learning. In accordance with the principles of RME, these interactive features encouraged students to construct mathematical concepts from realistic situations and progressively transform their intuitive understanding into formal mathematical knowledge.



Keterangan:
Storyboard Menu Utama
1. Tombol Home
2. Tombol Menu Utama
3. Tombol Petunjuk
4. Judul Halaman
5. Tombol Musik Off
6. Tombol Musik On
7. Tombol Keluar
8. Tombol Kompetensi
9. Tombol Materi
10. Tombol Video
11. Tombol Diskusi
12. Tombol Permainan
13. Tombol Evaluasi

Keterangan:
Storyboard Menu Materi
1. Tombol Home
2. Tombol Menu Utama
3. Tombol Petunjuk
4. Judul Halaman
5. Tombol Musik Off
6. Tombol Musik On
7. Tombol Keluar
8. Tombol Materi Peluang Apersepsi
9. Tombol Materi Peluang Majemuk
10. Tombol Materi Peluang Kejadian Saling Lepas
11. Tombol Materi peluang Kejadian Tidak Saling Lepas
12. Tombol Materi Peluang Saling Bebas
13. Tombol Materi Peluang Bersyarat

Keterangan:
Storyboard Menu Materi
1. Tombol Home
2. Tombol Menu Utama
3. Tombol Petunjuk
4. Tombol Menu Materi
5. Judul Halaman
6. Tombol Musik Off
7. Tombol Musik On
8. Tombol Keluar
9. Isi Materi
10. Tombol Kesimpulan
11. Tombol Contoh Soal
12. Tombol Latihan Soal
13. Tombol Halaman Selanjutnya
14. Tombol Halaman Sebelumnya

Keterangan:
Storyboard Permainan
1. Tahap
2. Judul Halaman
3. Nilai
4. Isi permainan
5. Tombol Halaman Selanjutnya

Figure 2. Storyboard of the mobile learning application.

The storyboard developed during the design stage served as the blueprint for translating instructional objectives and the principles of Realistic Mathematics Education (RME) into an interactive mobile learning environment. It defined the organization of menus, navigation paths, learning sequences, and multimedia elements incorporated into the application. Based on this design framework, the mobile learning application was developed using Smart Apps Creator 3 and equipped with various features, including learning materials, instructional videos, discussion forums, educational games, and evaluation activities. The resulting user interfaces are presented in Figure 3, illustrating how the conceptual design was transformed into a functional learning medium that supports students' understanding of compound probability.

(a) Main menu | (b) User guide | (c) Learning materials | (d) Interactive exercises | (e) Evaluation page | (f) Educational games

Figure 3. User interfaces of the RME-based mobile learning application: (a) main menu; (b) user guide; (c) learning materials; (d) interactive exercises; (e) evaluation page; and (f) educational games.

Integration of Realistic Mathematics Education Principles

The instructional design of the application explicitly incorporated the principles and characteristics of Realistic Mathematics Education. The learning process began with contextual problems closely related to students' daily experiences and gradually introduced mathematical representations through diagrams, visual simulations, and interactive exercises. The instructional sequence was organized progressively, beginning with problem exploration, followed by the development of students' solution strategies, and ending with formal conceptual generalization. Each learning section included contextual examples, guided exercises, automatic feedback, and reflection activities to support students' independent knowledge construction.

The mapping between the principles of RME and the components of the mobile learning application is presented in Table 1.

Table 1. Mapping of RME Principles and Mobile Learning Components

RME Principle	Learning Characteristic	Mobile Learning Component
Guided reinvention and progressive mathematization	Use of models	Instructional videos and visual representations
Guided reinvention and progressive mathematization	Students' contribution	Exercises and evaluation activities
Didactical phenomenology	Use of context	Contextual problems and introductory activities
Self-developed models	Interactivity	Educational games and discussion forums

Product Validity

Before classroom implementation, the mobile learning application underwent expert validation involving a mathematics education lecturer from Universitas Negeri Malang and an experienced mathematics teacher. The lecturer assigned a validity score of 82.73%, whereas the teacher assigned a score of 90.00%. The average validity score reached 86.37%, indicating that the developed product satisfied the criteria of "very valid" and was therefore suitable for implementation in mathematics learning.

Table 2. Product Validation Results

Validator	Obtained Score	Maximum Score	Percentage (%)	Category
Mathematics education lecturer	91	110	82.73	Valid
Mathematics teacher	99	110	90.00	Very valid
Average	–	–	**86.37**	**Very valid**

The validators highlighted the relevance of the learning content to the instructional objectives, the accuracy of compound probability concepts, and the consistency of the application with the principles of Realistic Mathematics Education. Nevertheless, several suggestions were provided, particularly regarding the excessive amount of text in certain sections. Consequently, revisions were made by simplifying textual explanations and enriching the interface with additional visual elements and illustrations.

The validation process also involved evaluating the practicality questionnaire and the achievement test. The questionnaire instrument achieved a validity score of 85%, while the achievement test obtained an average score of 90%, indicating that both instruments were suitable for subsequent data collection.

Table 3. Instrument Validation Results

Instrument	Percentage (%)	Category
Student and teacher response questionnaire	85.00	Valid
Achievement test	90.00	Very valid

In addition to evaluating the validity of the instruments, the expert review process provided several suggestions for improving the quality of the developed mobile learning application. These recommendations were incorporated into the product revision process prior to classroom implementation, as summarized in Table 4.

Table 4. Summary of Product Revisions

Aspect	Initial Condition	Revision
Learning materials	Text-heavy presentation	Additional illustrations and simplified explanations
Multimedia elements	Limited contextual support	Integration of contextual videos and audio
Interface design	Basic layout	Improved visual organization and navigation

Product Practicality

The practicality of the mobile learning application was assessed through questionnaires administered to students and teachers after the implementation stage. The classroom trial involved 35 eleventh-grade students and was conducted over three instructional meetings. During the implementation, students used the application individually and collaboratively to complete contextual tasks and learning activities related to compound probability.

Figure 8. Students using the mobile learning application during classroom implementation.

Student responses yielded an average practicality score of 84.09%, while teacher responses reached 85.71%, resulting in an overall average score of 84.90%. These findings indicate that the application met the criteria for practicality and was suitable for classroom use.

Table 5. Overall Practicality Results

Respondent Group	Percentage (%)	Category
Students	84.09	Practical
Teacher	85.71	Very practical
Average	84.90	Practical

The detailed student responses showed that the highest scores were obtained for language clarity (88.57%), visual readability (85.71%), flexibility of access (85.14%), and the ability of the application to enhance classroom engagement (85.71%). Meanwhile, the lowest score was associated with students' willingness to use similar applications for other mathematics topics (80.57%).

Table 6. Selected Student Response Indicators

Indicator	Percentage (%)
Clear instructions and guidance	82.86
Flexible access anytime and anywhere	85.14
Systematic presentation of materials	85.14
Ease of understanding concepts	84.00
Attractive visual design	83.43
Increased engagement and participation	85.71
Clear language use	88.57
Average practicality score	84.09

Teachers assigned the highest ratings to the clarity of instructions and the flexibility of application use, both reaching 100%. Teachers also considered the application capable of supporting active learning and recommended its use by other mathematics teachers.

Table 7. Teacher Response Results

Indicator	Percentage (%)
Ease of access through smartphones	80
Clarity of instructions	100
Ease of navigation	80
Support for student engagement	80
Alignment with RME principles	80
Flexibility of use	100
Potential for wider implementation	80
Average practicality score	85.71

In addition, several participants provided recommendations for further development. Teachers emphasized the need to consider students' internet access and smartphone specifications, whereas students suggested improving the quality of videos and audio and making the application available through the Google Play Store.

Product Effectiveness

The effectiveness of the mobile learning application was evaluated using students' achievement test scores following the implementation phase. The classroom trial was conducted across three meetings held on July 28, August 4, and August 11, 2025. During these sessions, students completed a series of learning activities related to compound probability, including understanding contextual problems, constructing mathematical representations, and solving exercises provided within the application.

The results revealed that 30 out of 35 students achieved scores above the Minimum Learning Competency Criteria (KKTP), corresponding to a mastery level of 85.71%. The average score reached 86.49, with student scores ranging from 59.4 to 100. Based on the predetermined effectiveness criteria, the developed mobile learning application was categorized as effective.

Table 8. Effectiveness Test Results

Indicator	Value
Number of students	35
Students achieving mastery	30
Students not achieving mastery	5
Mastery percentage	85.71%
Mean score	86.49
Score range	59.4–100
Category	Effective

Analysis of students' responses indicated that those who failed to achieve mastery commonly experienced difficulties in identifying relevant information, distinguishing among different probability events, applying formulas appropriately, and systematically reviewing their answers. Despite these challenges, classroom observations showed that students actively participated in learning activities and demonstrated positive engagement with contextual tasks embedded in the application.

Evaluation and Product Refinement

The final stage of the study focused on evaluating the overall quality of the application and implementing continuous improvements. Revisions were made to the storyboard and multimedia components to ensure alignment with the instructional objectives and the principles of Realistic Mathematics Education. Several improvements included simplifying textual explanations, enriching contextual materials with videos and audio, and enhancing visual elements to improve students' learning experiences.

Several technical challenges emerged during implementation. Specifically, the installation process required stable internet access because of the relatively large application file size. In addition, certain devices experienced reduced performance when loading multimedia content. These issues were addressed by distributing the application offline and providing alternative internet access during classroom implementation. Overall, the evaluation findings demonstrated that the developed mobile learning application fulfilled the criteria of validity, practicality, and effectiveness and can therefore be used as an alternative instructional medium for teaching compound probability in vocational high schools.

Discussion

The findings indicate that the mobile learning application developed through the ADDIE framework achieved a high level of validity, demonstrating that the integration of mobile technology and Realistic Mathematics Education (RME) principles resulted in an instructional product that was pedagogically and technically appropriate for vocational mathematics learning. This outcome confirms Bopardikar et al. (2021) and Mendoza et al. (2022) proposition that systematic instructional design facilitates coherence among learning objectives, teaching strategies, and assessment procedures. More importantly, the positive validation scores suggest that contextual mathematical experiences can be effectively translated into digital learning environments without diminishing conceptual depth. Previous studies have similarly reported that instructional media developed through structured design models tend to exhibit strong feasibility and instructional quality (Ariza, 2023; Fischer et al., 2022). However, the present study extends this body of research by demonstrating that mobile learning is not merely a technological tool but can function as a medium for facilitating mathematical meaning-making when grounded in a coherent pedagogical framework. Consequently, the validity findings reinforce the argument that instructional technology becomes educationally meaningful only when supported by sound theoretical principles.

The high validity of the developed application also provides empirical support for the central assumptions of RME theory. According to Rehman et al. (2024), mathematics should be viewed as a human activity in which learners actively construct knowledge through engagement with meaningful contexts. Koskinen & Pitkäniemi (2022) further argued that learning occurs through processes of guided reinvention and progressive mathematization, enabling students to move from informal reasoning toward formal mathematical understanding. In the present study, these principles were operationalized through contextual problems, visual representations, interactive tasks, and opportunities for reflection embedded within the application. Rather than introducing probability formulas directly, students were encouraged to investigate authentic situations and gradually formalize their mathematical thinking. Similar conclusions have been reported by recent studies on RME-based digital learning environments, which found that contextualized instruction strengthens conceptual understanding and mathematical reasoning (Arifin & Efriani, 2025; Koerunnisa et al., 2025). Nevertheless, the present findings contribute a broader perspective by demonstrating that the processes of mathematization proposed by RME remain effective within autonomous and technology-mediated learning environments.

Another important finding concerns the high level of practicality perceived by both students and teachers, indicating that the application was not only accessible but also relevant to classroom needs. The practical value of the application can be interpreted through contemporary theories of mobile learning, which emphasize flexibility, learner autonomy, and ubiquitous access to educational resources. Nikolopoulou (2023) argued that mobile technologies reshape learning by removing temporal and spatial constraints, thereby enabling more individualized and self-regulated learning experiences. Likewise, Hidayat-Ur-Rehman (2024) found that mobile applications enhance students' perceptions of competence and autonomy, two essential components of effective learning. In the present study, the positive responses toward navigation, accessibility, and instructional clarity suggest that students were able to interact with mathematical content more independently. This finding supports previous research showing that mobile learning environments can improve students' engagement and participation across different educational contexts (Carroll et al., 2021; Garzón et al., 2025).

Beyond issues of accessibility, the strong practicality ratings underscore the pedagogical significance of multimedia integration in mathematics education. The combination of videos, audio explanations, interactive exercises, and educational games appears to have created an environment that stimulated students' interest and sustained their engagement throughout the learning process. From the perspective of Cognitive Theory of Multimedia Learning, the integration of verbal and visual representations reduces unnecessary cognitive load and facilitates deeper conceptual processing. Interactive features such as drag-and-drop activities, connect-the-dots tasks, and immediate feedback may have supported students in organizing information and constructing relationships among mathematical concepts. Previous studies have consistently demonstrated that multimedia-based mobile learning enhances motivation and participation by presenting information in multiple formats (Abdulrahaman et al., 2020; Staneviciene & Žekienė, 2025). However, unlike many earlier studies that focused primarily on technological usability, the present research suggests that multimedia features become educationally meaningful only when integrated with contextual learning principles. Thus, the effectiveness of digital learning environments cannot be attributed solely to technological sophistication but must also be understood as the outcome of deliberate pedagogical design.

The effectiveness findings further suggest that the combination of mobile learning and RME supported students' conceptual engagement with compound probability. More than eighty-five percent of the participants achieved the minimum learning mastery criterion, indicating that the application provided an instructional environment conducive to understanding complex probabilistic relationships. This finding aligns with RME theory, which proposes that mathematical concepts become more accessible when learners are guided from concrete experiences toward abstract representations. Compound probability is widely recognized as a challenging topic because students must coordinate multiple events, distinguish among probabilistic structures, and understand how different conditions influence outcomes. Previous studies have shown that students often rely on memorization strategies rather than conceptual reasoning when solving probability problems (Carpenter et al., 2020; Reyna & Brainerd, 2023). The present findings suggest that contextual scenarios, visual models, and guided activities may support students in interpreting these relationships more meaningfully. Nevertheless, because this study employed a developmental design without a control group or pretest–posttest comparison, the findings should be interpreted as evidence that the application supported conceptual understanding rather than conclusively improved learning outcomes.

A deeper analysis reveals that the effectiveness of the application may be explained by the interaction between mobile learning affordances and the cognitive mechanisms underlying mathematical learning. Contemporary research suggests that digital technologies can strengthen conceptual understanding by reducing cognitive load, providing immediate feedback, and enabling learners to revisit instructional materials repeatedly (Huang & Chen, 2025; Liu et al., 2026). In the present study, the visualization of probability concepts through videos and animations likely reduced students' cognitive burden when interpreting abstract relationships among events. Furthermore, the availability of instant feedback enabled students to identify misconceptions and refine their reasoning processes during problem-solving activities. These findings extend previous research by suggesting that mobile technologies do not merely deliver mathematical content but also facilitate the processes of guided reinvention and reflection that constitute the core of RME. Accordingly, the present study contributes to the theoretical understanding of how digital environments can mediate mathematical thinking and conceptual development.

Several contextual factors may also explain the positive outcomes observed in this study. First, the participants were vocational high school students who were already familiar with smartphones and digital communication, which may have facilitated the acceptance and use of mobile learning. Second, the study was conducted within the framework of the Indonesian Merdeka Curriculum, which emphasizes contextual learning, student agency, and independent exploration. These curricular principles are highly compatible with both RME and mobile learning approaches. Third, the application incorporated real-time feedback mechanisms that encouraged students to monitor their own learning progress and revise their strategies when necessary. To (2022) and Zhang & Hyland (2022) similarly argued that immediate feedback promotes learner responsibility and increases engagement with academic tasks. Therefore, the effectiveness of the developed application appears to result not only from technological features but also from the alignment between pedagogical design, learner characteristics, and curricular demands.

Despite these positive findings, several limitations embedded within the implementation context warrant critical consideration. The application required stable internet connectivity during installation and exhibited reduced performance on devices with lower specifications, highlighting the continuing influence of technological inequality on the success of mobile learning initiatives. Okai-Ugbaje et al. (2022) emphasized that the educational potential of mobile technologies remains contingent upon access to adequate infrastructure and digital resources. Moreover, the application was designed exclusively for Android devices, thereby limiting its accessibility across different operating systems. These constraints suggest that the effectiveness of mobile learning cannot be separated from broader socioeconomic and technological conditions. Future research should therefore investigate cross-platform compatibility and examine how differences in technological access influence the implementation and sustainability of mobile learning in diverse educational settings.

Taken together, this study contributes to the global literature on mathematics education by addressing an important gap in previous research. Existing studies have often examined mobile learning and Realistic Mathematics Education separately, while empirical investigations that integrate mobile technologies, contextual mathematization, compound probability, and vocational education remain limited. Unlike earlier studies that primarily emphasized technological innovation, the present research demonstrates how mobile learning can function as a medium for supporting mathematical meaning-making through the principles of guided reinvention and progressive mathematization. Theoretically, the findings extend RME by illustrating that processes of mathematization can be mediated through interactive digital environments. Practically, the study provides evidence that mobile learning applications grounded in established pedagogical theories can support meaningful mathematics learning in vocational schools. More broadly, the study offers a new perspective on the relationship between pedagogy and technology by showing that digital transformation in education requires not only technological advancement but also the thoughtful integration of learning theories capable of addressing persistent challenges in mathematics education.

Implications

The findings of this study have several implications for mathematics education, particularly in vocational high schools. From a pedagogical perspective, the integration of mobile learning with the Realistic Mathematics Education (RME) approach provides an alternative instructional strategy that can bridge the gap between abstract mathematical concepts and students' real-life experiences. The developed application demonstrates that contextual problems, interactive multimedia, and game-based activities can enhance students' engagement and support the construction of conceptual understanding in learning compound probability. Practically, the application offers teachers a flexible and accessible learning medium that can complement classroom instruction and promote student-centered learning. Furthermore, this study contributes to the growing body of literature on technology-enhanced mathematics education by providing empirical evidence regarding the validity, practicality, and effectiveness of RME-based mobile learning. Nevertheless, future research is needed to investigate the long-term impact of the application, expand its implementation to different educational settings, and integrate more advanced technologies to optimize mathematics learning outcomes.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the implementation of the developed mobile learning application was limited to 35 eleventh-grade students from a single vocational high school in Malang, which may restrict the generalizability of the results to different educational contexts and student populations. Second, the application was designed specifically for Android devices and required adequate internet connectivity and device specifications, creating technical challenges during installation and use. Third, the evaluation of effectiveness was based on students' learning outcomes after the implementation stage without examining the long-term retention of conceptual understanding or comparing the results with those of conventional instructional methods. Finally, the developed application focused exclusively on the topic of compound probability; therefore, further studies are needed to investigate its applicability to other mathematical topics and to explore the integration of more advanced technological features and learning management systems.

Suggestions

Based on the findings of this study, several suggestions can be proposed. For teachers, the developed mobile learning application may serve as an alternative instructional medium to support the teaching of compound probability and to create more contextual, interactive, and student-centered mathematics learning environments. Schools are encouraged to improve technological infrastructure, including internet access and device availability, to facilitate the effective implementation of mobile learning. Future researchers are recommended to conduct studies involving larger and more diverse samples, apply experimental designs to compare learning outcomes with conventional instruction, and examine the long-term effects of mobile learning on students' mathematical understanding and motivation. In addition, further development could expand the application to other mathematical topics and integrate advanced features, such as learning management systems, adaptive feedback, and cross-platform compatibility, to enhance its accessibility and educational impact.

CONCLUSION

This study developed an Android-based mobile learning application grounded in the principles of Realistic Mathematics Education (RME) to support the learning of compound probability among vocational high school students. Developed through the ADDIE model, the application integrated contextual problems, multimedia elements, interactive activities, and educational games to facilitate students' conceptual understanding and engagement. The findings demonstrated that the developed product met the criteria of validity, practicality, and effectiveness, as evidenced by an average validity score of 86.37%, practicality scores of 84.09% from students and 85.71% from the teacher, and a learning mastery rate of 85.71% with a mean achievement score of 86.49. These results indicate that the integration of mobile learning and RME provides a meaningful and flexible learning environment that supports students' transition from contextual reasoning to formal mathematical concepts. Despite several technical limitations related to internet connectivity and device specifications, the developed application has considerable potential to serve as an innovative instructional medium in vocational mathematics education. Future studies are encouraged to expand the implementation to broader educational contexts and explore the integration of mobile learning with other mathematical topics and emerging educational technologies.

AUTHOR CONTRIBUTIONS STATEMENT

TL Conceptualization, Methodology, Software, Investigation, Data curation, Formal analysis, Visualization, Writing – original draft, and Project administration. **NO** Methodology, Validation, Investigation, Resources, Writing – review & editing, and Supervision. **D** Conceptualization, Validation, Formal analysis, Supervision, Writing – review & editing, Funding acquisition (if applicable), and Final approval of the manuscript.

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