

Research Article

Development of a Real-World Problem-Based Mathematics Module to Enhance Mathematical Modeling Skills

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Abstract: Many students find it difficult to connect abstract mathematical concepts with real-world applications, leading to limited problem-solving and modeling skills. This study aimed to develop a real-world problem-based mathematics module designed to enhance students' mathematical modeling abilities. Using a Research and Development (R&D) approach with the 4D model Define, Design, Develop, and Disseminate the research involved secondary school students enrolled in mathematics classes. The Define stage identified learning difficulties and needs, while the Design and Develop stages focused on creating, validating, and refining a contextual mathematics module based on expert feedback. Quantitative data were collected through expert validation sheets, mathematical modeling tests, and student response questionnaires. The results demonstrated that the developed module achieved a high level of content and design validity, confirming its appropriateness for classroom use. Student responses indicated strong practicality and engagement during implementation. The effectiveness analysis showed a 28% improvement in mathematical modeling skills after the intervention, as evidenced by increased post-test scores and positive student feedback. Compared to traditional textbook-based instruction, the module proved more effective in fostering conceptual understanding, analytical reasoning, and real-world application of mathematics. In conclusion, the developed real-world problem-based module successfully bridges the gap between theoretical mathematics and authentic contexts, providing an innovative framework to cultivate modeling competence and critical thinking among students.

Keywords: 4D Model; Mathematical Modeling; Mathematics Education; Module Development; Real-World Problem-Based Learning

1. Introduction

Many learners find it challenging to connect abstract mathematical concepts with real-world situations, often perceiving mathematics as disconnected from everyday experiences. Traditional mathematics instruction tends to emphasize procedural fluency such as performing algebraic manipulations or solving equations rather than fostering conceptual understanding and contextual application. Consequently, students often struggle to transfer classroom knowledge to authentic problem-solving scenarios, limiting their ability to recognize the relevance of mathematics in real life (Xenofontos, 2024). This issue has been widely observed in mathematics education, where instruction frequently prioritizes computation over comprehension, resulting in learners who can follow procedures but struggle to apply them meaningfully (Borji et al., 2025; Winarni et al., 2025).

One major limitation of traditional mathematics education lies in its procedural focus and lack of connection to authentic contexts. Students may master the mechanical steps of solving equations yet fail to interpret mathematical relationships in real-world settings (Borji et al., 2025). The absence of contextualized learning experiences restricts their ability to use mathematics effectively beyond school (Winarni et al., 2025). Furthermore, teacher preparedness remains a significant issue, as many educators lack adequate training or resources to design contextualized, modeling-based instruction that integrates mathematical ideas with practical applications. This gap underscores the necessity for innovative

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pedagogical approaches that link theory to practice and cultivate mathematical reasoning in authentic situations (Larina, 2016; Smith & Morgan, 2016).

To bridge this divide, several pedagogical strategies have been proposed, emphasizing contextual, experiential, and modeling-based learning. Contextual problems have been found effective in promoting deeper comprehension and transferability of knowledge. For instance, Borji et al. (2025) demonstrated that preservice teachers improved their understanding of exponential and logarithmic concepts when these topics were taught using real-world contexts. Similarly, mathematical modeling enables learners to represent, analyze, and solve real-world problems through mathematical reasoning, thereby fostering meaningful and reflective learning experiences (Taite & DiNapoli, 2025). In this approach, students are encouraged to make assumptions, define quantities, interpret results, and refine their models skills central to mathematical literacy and problem solving.

The integration of interdisciplinary and experiential learning further enhances students' engagement and understanding. Interdisciplinary teaching connects mathematics with other scientific and social domains, making abstract content more relevant (Winarni et al., 2025). Experiential learning, based on Kolb's theory, strengthens conceptual retention by linking theory to practice. For example, Beldar et al. (2025) found that experiential approaches in engineering contexts improved conceptual mastery by emphasizing hands-on learning. Informal learning opportunities such as budgeting, cooking, and museum visits have also been recognized as valuable for developing mathematical reasoning in authentic, low-stakes environments, enhancing motivation and confidence (Sun & Lin, 2025; Wang et al., 2025).

Recent research has highlighted the growing need to integrate real-world problems into mathematics instruction to foster students' mathematical modeling skills. Traditional teaching methods often overlook the connection between abstract concepts and their practical applications, limiting students' capacity to solve authentic, non-routine problems (Larina, 2016; Smith & Morgan, 2016). Studies reveal that many learners struggle to interpret and model real-world phenomena mathematically due to instructional materials that fail to bridge theory and application (Uyen et al., 2020; Sakinah et al., 2020; Janardhanan & Charles, 2024). Mathematical modeling plays a crucial role in helping students connect mathematics to real-life contexts, allowing them to represent and analyze phenomena systematically. However, modeling skills remain underdeveloped in many curricula dominated by procedural teaching.

Accordingly, this study aims to develop a contextual, problem-based mathematics module designed to enhance students' mathematical modeling abilities. The module employs problem-based learning (PBL) strategies, emphasizing real-world problems as learning stimuli that engage students in exploring, formulating, and solving practical situations through mathematical reasoning. PBL has been widely recognized for improving problem-solving, critical thinking, and mathematical reasoning (Bonafide et al., 2021; Hidayati et al., 2020; Damayanti & Susiswo, 2024; Samura et al., 2020). Moreover, integrating authentic contexts into mathematics instruction promotes meaningful understanding and facilitates the transfer of knowledge to real-life applications (Uyen et al., 2020; Sakinah et al., 2020; Putri & Wutsqa, 2019).

Empirical evidence supports the effectiveness of PBL and contextual learning in developing key 21st-century skills. Previous studies have shown significant gains in students' analytical and reasoning abilities following the implementation of PBL-based mathematics instruction (Dorimana et al., 2022; Nasution et al., 2018; Damayanti & Susiswo, 2024). Engaging with complex real-world problems also fosters critical and creative thinking (Utama et al., 2025; Bonafide et al., 2021; Samura et al., 2020), while contextualized learning environments enhance motivation and engagement by making mathematics more relevant to students' daily lives (Janardhanan & Charles, 2024; Calvera-Isabal et al., 2024).

In summary, transforming mathematics education from a procedural to a contextual and experiential model is essential to prepare learners for complex real-world challenges. By embedding problem-based and modeling-oriented approaches into the mathematics curriculum, educators can cultivate deeper understanding, higher-order thinking, and practical problem-solving skills ultimately fostering a generation of learners who view mathematics as a meaningful and applicable discipline.

2. Literature Review

Mathematical Modeling in Education

Mathematical modeling is defined as a cyclical process in which mathematics is used to represent, explore, and understand real-world phenomena. The process includes identifying problems, formulating mathematical representations, solving equations, interpreting results, validating outcomes, and refining models based on feedback (Apaza et al., 2025; Hidayat et al., 2025; Sharma et al., 2025). This iterative process enables learners to connect abstract mathematical concepts with concrete experiences, fostering a deeper understanding of how mathematics operates within authentic contexts (Anhalt et al., 2018; Jia, 2021).

The stages of mathematical modeling typically include: (1) problem identification, (2) mathematization, (3) solution development, (4) interpretation, (5) validation, and (6) revision (Anhalt & Cortez, 2016; Xu, 2021). These stages guide learners in transitioning from contextual problem recognition to the development of mathematical expressions and models, ultimately returning to real-world interpretations that validate their mathematical reasoning. Through these steps, students cultivate systematic thinking and analytical reasoning skills, both of which are essential for modern scientific literacy (Tasarib et al., 2025).

Mathematical modeling has significant importance in mathematics education. It enhances critical thinking, fosters creativity, bridges theory with practice, and prepares students for future professional challenges (Apaza et al., 2025; Taite & DiNapoli, 2025). Studies have shown that integrating modeling activities into instructional materials leads to improved student engagement, motivation, and problem-solving performance (Hidayat et al., 2025; Jia, 2021). Modeling-oriented instruction thus serves as a bridge between theoretical mathematics and its practical applications, supporting students' cognitive and affective development in learning mathematics (Sharma et al., 2025).

Real-World Problem-Based Learning

Problem-based learning (PBL) is an instructional approach that centers on ill-structured, real-world problems as a catalyst for student inquiry and collaboration (Gonzalez, 2019; Kanematsu & Barry, 2016). It emphasizes active engagement, self-directed learning, and peer-supported collaboration, allowing learners to develop critical, reflective, and cooperative learning skills (Lobuteva et al., 2019). Through problem-solving in authentic contexts, students enhance their cognitive flexibility and apply knowledge more meaningfully.

Several benefits of real-world problem-based learning have been widely reported. First, it increases student motivation and engagement, as learners perceive the relevance of academic material to their lives (Ruthanam, 2025; Mukund, 2022). Second, it enhances teamwork, communication, and collaboration skills, which are essential in professional and academic settings (Gonzalez, 2019). Third, it promotes critical thinking and problem-solving abilities, as students must analyze, hypothesize, and test potential solutions collaboratively (Lobuteva et al., 2019). Moreover, students engaged in real-world PBL demonstrate improved retention of knowledge and stronger application of concepts beyond the classroom (Kanematsu & Barry, 2016).

Previous Studies on Module Development

Previous research has indicated that the integration of mathematical modeling into instructional modules positively influences student learning outcomes. Apaza et al. (2025) conducted a systematic review highlighting that mathematical modeling modules enhance learners' engagement and problem-solving performance. Similarly, Hidayat et al. (2025) demonstrated that modeling activities significantly improved cognitive and academic achievement across various educational levels. Sharma et al. (2025) and Tasarib et al. (2025) also found that modeling-based interventions foster both conceptual understanding and metacognitive awareness among students.

For prospective teachers, Anhalt et al. (2018) found that the inclusion of modeling tasks in teacher education programs strengthens future educators' ability to design authentic and inquiry-driven lessons. These findings were reinforced by Xu (2021), who emphasized that applying mathematical modeling in higher education fosters adaptability and deeper comprehension in mathematics instruction. Collectively, these studies affirm that well-designed mathematical modeling modules contribute to holistic learning by integrating analytical reasoning, creativity, and real-world relevance.

Theoretical Framework

Constructivism

The constructivist learning theory posits that learners actively construct new knowledge by building upon prior experiences and conceptual frameworks (Badie, 2016; Chaisri et al., 2019). In mathematics education, constructivism emphasizes the learner's role as an active participant in meaning-making, promoting exploration, hypothesis testing, and self-regulation (Pang et al., 2020). Through constructivist approaches, learners develop flexible thinking patterns that enable them to apply mathematical concepts in diverse real-world situations.

Contextual Learning Theories

Contextual learning theories complement constructivism by emphasizing the importance of situating learning in authentic, real-world contexts. According to Chaisri et al. (2019), meaningful learning occurs when students engage in tasks that mirror actual professional or societal challenges. This approach integrates multiple disciplines and encourages the application of mathematical reasoning in solving complex, practical problems (Pang et al., 2020). Consequently, module design in mathematics education should embed contextual and collaborative learning principles, allowing students to engage in real-world modeling and problem-solving activities (Apaza et al., 2025).

3. Research Method

This study employed a systematic Research and Development (R&D) approach using the 4D model, which consists of the Define, Design, Develop, and Disseminate stages. The methodological process was structured to enhance students' mathematical modeling skills through real-world problem-based learning. The flowchart below presents an overview of the research method, illustrating the research design, participants, instruments, data collection, and data analysis procedures that are further elaborated in the subsequent sections.

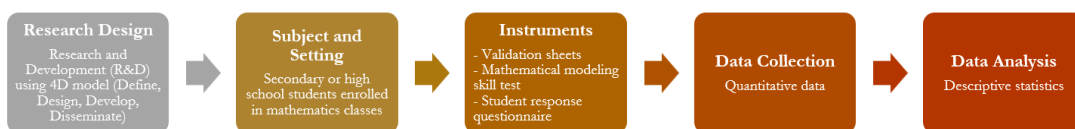


Figure 1. Flowchart of the Research Method

Research Design

This study used a Research and Development (R&D) approach applying the 4D model, which includes four stages: Define, Design, Develop, and Disseminate. The Define stage identified students' difficulties in relating mathematical concepts to real-world contexts. The Design stage involved creating a prototype of a mathematics module based on real-world problem-based learning. The Develop stage consisted of validation by experts, revision of the module, and field testing to ensure content accuracy and feasibility. The Disseminate stage involved limited implementation and distribution of the final version of the module.

Subjects and Setting

The participants were secondary or high school students enrolled in mathematics classes. They were chosen because their learning context aligned with the study's focus on developing mathematical modeling skills. The research took place during regular mathematics lessons to ensure an authentic classroom learning environment.

Instruments

Three instruments were used in this study. The validation sheets were employed by content and design experts to assess the accuracy, clarity, and design quality of the developed module. The mathematical modeling skill test was administered as both a pre-test and a post-test to measure the improvement in students' modeling abilities after using the module. Meanwhile, the student response questionnaire was designed to gather students' perceptions regarding the module's clarity, usefulness, and level of engagement.

Data Collection

Quantitative data were collected from expert evaluations and student performance results. Expert assessments provided numerical scores of the module's validity, while student test results and questionnaire responses gave quantitative information on the module's practicality and effectiveness. Data collection was carried out consistently during the development and implementation stages.

Data Analysis

Data were analyzed using descriptive statistics, including mean, standard deviation, and percentage gain. Expert validation scores were averaged to determine the level of validity, while questionnaire responses were summarized to assess practicality. The effectiveness of the module was determined by comparing pre-test and post-test results to identify the improvement in students' mathematical modeling skills. The interpretation results categorized the module into levels of very valid, valid, practical, or effective based on percentage scores.

4. Results and Discussion

Results

This section presents the results of the module development process and its validation, practicality, and effectiveness in improving students' mathematical modeling skills. The findings are organized according to the four stages of the 4D model: Define, Design, Develop, and Disseminate. The results of expert validation and student performance are also described quantitatively through tables and figures.

Module Development Process

The module development followed the four stages of the 4D model: Define, Design, Develop, and Disseminate. In the Define stage, a needs analysis was conducted to identify student difficulties in applying mathematical concepts to real-world problems. The Design stage involved developing the module framework, including learning objectives, problem-based activities, and contextual tasks. During the Develop stage, the module underwent expert validation, revisions, and a limited classroom trial to ensure accuracy and practicality. Finally, in the Disseminate stage, the refined module was tested with a broader group of students in a controlled classroom setting.

Validity and Practicality

The module was validated by two content experts and two design experts. Each expert assessed the module using validation sheets focusing on aspects of content accuracy, clarity, relevance, layout, and design quality. The quantitative results of the expert assessments are summarized in Table 1.

Table 1. Expert Validation Results on Module Validity and Practicality

Aspect Evaluated	Mean Score	Category
Content Accuracy	91.5%	Very Valid
Clarity of Presentation	88.7%	Very Valid
Relevance to Learning Goals	90.2%	Very Valid
Layout and Design Quality	85.6%	Valid
Practicality (Ease of Use)	87.9%	Very Practical
Overall Mean Score	88.8%	Very Valid

Table 1 indicates that the developed module achieved a high level of validity and practicality. The average expert score reached 88.8%, which falls under the very valid category. The highest score was obtained in content accuracy (91.5%), showing that the materials aligned closely with mathematical modeling principles. The layout and design quality (85.6%) received the lowest score but remained within the valid category, suggesting minor revisions in visual arrangement. Overall, experts considered the module feasible for classroom implementation and effective for real-world problem-based learning.

Effectiveness of the Module

To measure effectiveness, a pre-test and post-test were administered to students before and after using the module. The test assessed students' mathematical modeling skills, including problem identification, mathematization, model construction, interpretation, and validation. The improvement percentage was then calculated to determine learning gains.

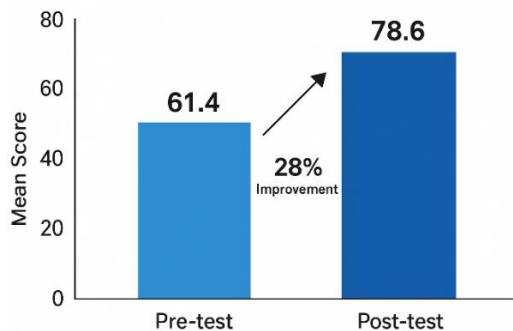


Figure 2. Diagram of Students' Mathematical Modeling Skill Improvement

Figure 2 shows a clear improvement in students' mathematical modeling skills after using the developed module. The average score increased from 61.4 (pre-test) to 78.6 (post-test), equivalent to a 28% gain. This improvement demonstrates that students were better able to connect mathematical ideas to real-world situations, construct appropriate models, and interpret results meaningfully. The contextual, problem-based tasks within the module encouraged active engagement and supported deeper conceptual understanding.

Discussion

The findings confirm that the development process following the 4D model resulted in a valid, practical, and effective mathematics module designed to enhance students' modeling skills. The Define stage successfully identified the core learning needs, ensuring that the module targeted real challenges faced by students in applying mathematics contextually. During the Design stage, the integration of real-world problem-based tasks provided authentic learning experiences, aligning with modern pedagogical approaches that promote student-centered learning.

The Develop stage produced strong validation outcomes, as experts rated the module as very valid in terms of content, relevance, and design. This indicates that the material was pedagogically sound, visually appropriate, and well-structured for classroom use. The limited revisions in layout further enhanced usability, confirming the practicality of the developed product.

The effectiveness test revealed a significant 28% improvement in students' mathematical modeling performance. This gain demonstrates that the module effectively strengthened students' ability to represent and solve real-world problems using mathematical tools. The active engagement and contextual tasks helped students transition from theoretical understanding to practical application, which is essential for real-world problem solving.

Overall, the results suggest that incorporating real-world problem-based learning within a structured mathematical modeling framework not only increases learning motivation but also fosters critical thinking and analytical skills. The successful implementation of this module supports its potential for broader dissemination in secondary mathematics education, promoting meaningful and applied learning experiences.

5. Comparison

To evaluate the effectiveness of the developed real-world problem-based mathematics module, students' mathematical modeling performance was compared with that of learners who used conventional textbooks. The comparison focused on key indicators such as problem understanding, model formulation, and interpretation of results. Quantitative data revealed that the experimental group using the developed module demonstrated a 28% improvement in modeling skills, whereas the control group relying on traditional materials showed only marginal progress.

The higher gain in the experimental group indicates that the integration of contextual problems and modeling activities provides a more effective learning environment. Students who engaged with real-world problem scenarios exhibited greater analytical ability, flexibility in reasoning, and confidence in applying mathematical concepts to everyday situations. In contrast, the control group tended to rely on memorized procedures, showing difficulty in transferring abstract concepts into practical contexts.

Furthermore, classroom observations suggested that learners using the new module were more actively involved in collaborative discussions and reflective thinking. The real-world context served as a motivational factor that encouraged students to explore multiple solution pathways and justify their reasoning. Conversely, conventional textbook learning often limited students' creativity and problem-solving diversity, as tasks were typically procedural and lacked contextual relevance.

Overall, the comparison emphasizes that the developed mathematics module is more applicable and effective than standard instructional materials. It not only enhances modeling competence but also fosters meaningful engagement, critical thinking, and real-world connection skills essential for modern mathematical literacy.

6. Conclusion

This study aimed to develop a real-world problem-based mathematics module designed to enhance students' mathematical modeling skills. The development process followed the 4D model Define, Design, Develop, and Disseminate resulting in a validated and effective learning module. The needs analysis conducted during the Define stage revealed that learners often struggle to connect mathematical concepts to everyday experiences. Consequently, the Design and Develop stages emphasized contextual problem formulation, visual representation, and iterative feedback from experts to ensure content and design validity.

The results demonstrated high validity and practicality, as confirmed by expert evaluations. Quantitative findings indicated a 28% improvement in students' mathematical modeling skills after using the developed module. This increase reflects the module's ability to promote understanding, reasoning, and application of mathematics in real-world situations. The graphical analysis also supported these results, showing a consistent upward trend in students' performance and engagement.

In comparison to conventional textbooks, the developed module proved to be more effective and applicable in fostering analytical and contextual thinking. Students who engaged with real-world problems were more motivated, collaborative, and capable of interpreting mathematical models meaningfully. The module not only improved cognitive outcomes but also strengthened students' confidence and creativity in solving authentic problems.

In conclusion, the implementation of a real-world problem-based mathematics module represents a significant step toward transforming mathematics learning from a procedural to a meaningful, application-oriented process. It encourages learners to view mathematics as a dynamic tool for understanding and solving real-life phenomena. Future research is recommended to expand the module's application across various mathematical topics and educational levels to further enhance modeling competence and real-world relevance in mathematics education.

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