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Development and evaluation of a flipbook-based project-based learning e-module to enhance mathematical communication skills in digital mathematics education

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Abstract

Background: The rapid advancement of digital technology in education requires students to develop not only problem-solving abilities but also effective mathematical communication skills. However, many students still experience difficulties in expressing mathematical ideas, reasoning, and solutions clearly. Consequently, innovative digital learning resources that integrate active learning approaches are needed to support meaningful mathematical communication.
Aims: This study aimed to develop and evaluate a Flipbook-based Project-Based Learning (PjBL) e-module and determine its validity, practicality, and effectiveness in enhancing students' mathematical communication skills.
Method: This research employed a Research and Development (R&D) approach using the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation stages. The e-module was developed by integrating Flipbook technology with PjBL activities. Data were collected through expert validation questionnaires, student response questionnaires, and classroom action research involving graduate students in Mathematics Education.
Results: The findings indicated that the developed e-module achieved a validity score of 81%, categorized as highly valid. The practicality assessment yielded a score of 85.7%, indicating that the module was highly practical for learning activities. Furthermore, students' mathematical communication skills improved from 74% in the first cycle to 82% in the second cycle, representing an 8% increase.
Conclusion: The Flipbook-based PjBL e-module was found to be valid, practical, and effective in improving students' mathematical communication skills and can serve as an innovative digital learning resource in mathematics education.

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INTRODUCTION

The primary objective of education is to create learning environments that enable students to actively develop their knowledge, skills, and potential through meaningful learning experiences. Achieving this objective requires the implementation of effective instructional strategies, appropriate learning resources, and supportive educational environments (Cheung et al., 2021; Khodadad, 2023; Timotheou et al., 2023). In the contemporary educational landscape, digital technology has become an integral component of teaching and learning processes (Makda, 2025; Zou et al., 2025). The integration of digital technology allows educational activities to become more flexible, interactive, and accessible to learners (Alenezi et al., 2023; Huda, 2023; Zou et al., 2025). In mathematics education, digital technology offers opportunities to present abstract concepts through visual, interactive, and multimedia-based representations (Mondal & Vijaykumar, 2025). These features can facilitate deeper conceptual understanding and promote active student participation

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during learning activities. Furthermore, digital learning environments encourage students to explore ideas independently and engage in problem-solving activities more effectively. The increasing demand for digital competence has also encouraged higher education institutions to integrate technology into various courses. As a result, students are expected not only to master disciplinary knowledge but also to develop the ability to utilize technology in meaningful learning contexts. Therefore, the development of innovative digital learning resources has become an important priority in contemporary mathematics education.

Digital Mathematics Education is one of the courses that emphasizes the utilization of digital technology to support mathematics teaching and learning. Observations conducted among students enrolled in this course revealed several challenges related to project-based assignments and the use of digital learning resources. Many students were able to describe the procedures required to develop educational products but encountered difficulties when asked to produce actual learning products. In addition, online learning activities frequently relied on instructional approaches similar to those used in conventional face-to-face classrooms, reducing the effectiveness of digital learning experiences (Foo et al., 2021; Gherheş et al., 2021; Lewohl, 2023; Thai et al., 2020). As a consequence, students often experienced difficulties in understanding course materials and completing project-based tasks independently. These challenges indicate that existing instructional resources have not fully supported the development of practical and project-oriented competencies. Moreover, there remains a need for learning materials that connect theoretical concepts with authentic applications relevant to students' professional contexts. Digital learning resources should provide clear guidance, structured activities, and opportunities for active engagement. Such resources are particularly important in courses that require students to design, develop, and evaluate digital learning products. Therefore, innovative instructional materials are needed to support meaningful learning experiences and improve student performance in digital mathematics education.

One learning resource that has considerable potential to address these challenges is the electronic module or e-module. E-modules provide structured learning materials that can be accessed independently and enriched with various multimedia features, including images, videos, animations, and interactive content (Alyusfitri et al., 2024). Among the available digital platforms, Flipbook technology offers an attractive learning environment by presenting materials in a digital book format with interactive navigation and multimedia integration. The effectiveness of e-modules can be enhanced further when combined with Project-Based Learning, a student-centered instructional model that emphasizes inquiry, collaboration, and authentic problem-solving. Through project activities, students are encouraged to apply knowledge in real-world contexts and develop practical solutions to meaningful problems. Project-Based Learning also provides opportunities for students to engage in discussion, reflection, and collaborative knowledge construction (Guo et al., 2020; Hussein, 2021; Mutanga, 2024; Sormunen et al., 2020; Williamson, 2023). These learning experiences are particularly relevant for developing mathematical communication skills, which involve expressing ideas, explaining reasoning, presenting solutions, and evaluating arguments. Mathematical communication plays a critical role in helping students articulate mathematical concepts through written explanations, visual representations, and symbolic expressions. Despite the recognized benefits of e-modules, Flipbook technology, and Project-Based Learning, their integration for improving mathematical communication skills remains relatively underexplored. Consequently, the development of a Flipbook-based Project-Based Learning e-module represents a promising approach to support mathematical communication within digital mathematics education.

Although mathematical communication skills have been widely recognized as an essential competency in mathematics education, previous studies have primarily focused on identifying factors influencing these skills, such as cognitive styles, gender differences, and the effectiveness of particular learning models, rather than developing integrated digital learning interventions

specifically designed to enhance mathematical communication (Chasanah et al., 2020; Tong et al., 2021). Similarly, research on Project-Based Learning (PjBL) has consistently demonstrated its positive impact on student achievement, engagement, collaboration, critical thinking, and overall learning outcomes; however, mathematical communication skills have rarely been examined as the primary outcome of PjBL implementation (Guo et al., 2020; Maros et al., 2023; Mutanga, 2024; C. Zhang et al., 2023). Furthermore, the growing body of literature on digital mathematics education has emphasized technology integration, digital learning environments, artificial intelligence, educational technologies, and technology-enhanced mathematics instruction, yet most studies focus on technology adoption and pedagogical perspectives rather than the development of specific instructional products that simultaneously support communication and active learning processes (Alabdulaziz, 2021; Drijvers & Sinclair, 2024; Engelbrecht & Borba, 2024; Viberg et al., 2023). Consequently, limited empirical evidence exists regarding the development and evaluation of Flipbook-based e-modules integrated with Project-Based Learning to improve mathematical communication skills, particularly within the context of digital mathematics education. Therefore, there remains a need to develop and evaluate an innovative Flipbook-based Project-Based Learning e-module that is valid, practical, and effective in enhancing students' mathematical communication skills.

This study aimed to develop and evaluate a Flipbook-based Project-Based Learning e-module for Digital Mathematics Education. The study sought to address instructional challenges related to students' difficulties in completing project-based tasks and communicating mathematical ideas effectively. Specifically, the research focused on designing a digital learning resource that integrates interactive multimedia features with project-oriented learning activities. The development process was conducted systematically to ensure that the resulting product met established quality standards. In addition, the study examined the validity of the developed e-module through expert evaluation. The practicality of the e-module was also investigated based on students' responses after implementation. Furthermore, the effectiveness of the e-module was assessed through improvements in students' mathematical communication skills. Particular attention was given to students' abilities to express mathematical ideas, communicate reasoning processes, use mathematical representations, and evaluate the arguments of others. The findings are expected to provide empirical evidence regarding the potential of Flipbook-based Project-Based Learning e-modules in mathematics education. Ultimately, this study contributes to the development of innovative digital learning resources that support meaningful learning and enhance mathematical communication skills in higher education.

LITERATURE REVIEW

Digital mathematics education has emerged as an important field of study in response to the rapid development of educational technologies and the increasing demand for technology-enhanced learning environments. The integration of digital technologies into mathematics instruction has transformed the ways students access information, interact with learning materials, and construct mathematical understanding (Cirneanu & Moldoveanu, 2024; Drijvers & Sinclair, 2024; Viberg et al., 2023). Digital learning environments provide opportunities for flexible learning that can occur beyond traditional classroom settings (Cheung et al., 2021; Müller & Mildenberger, 2021; Valtonen et al., 2021). Through the use of multimedia resources, students can engage with mathematical concepts using multiple representations and interactive experiences. The availability of digital learning resources also supports self-paced learning and individualized instruction. Furthermore, technology-enhanced mathematics learning encourages students to participate more actively in knowledge construction processes. Digital tools can facilitate visualization, exploration, and

experimentation with mathematical concepts that are often difficult to understand through conventional instruction (Cirneanu & Moldoveanu, 2024; Medina Herrera et al., 2024; Ziatdinov & James R. Valles, 2022). As a result, digital mathematics education has become increasingly important in preparing students for the demands of contemporary society. The effectiveness of digital learning environments depends not only on the technology itself but also on the pedagogical approaches that guide its implementation. Therefore, the development of innovative digital learning resources remains a critical area of research in mathematics education.

One of the most widely adopted digital learning resources in contemporary education is the electronic module or e-module. E-modules are designed to provide structured learning materials that can be accessed independently through digital devices (Delita et al., 2022). Unlike conventional printed modules, e-modules can incorporate multimedia elements such as images, animations, videos, hyperlinks, and interactive activities. These features allow learners to experience more engaging and meaningful learning processes. The flexibility offered by e-modules enables students to learn according to their individual needs and learning pace. Among various e-module platforms, Flipbook technology has gained attention because it presents learning content in an interactive digital book format. Flipbook-based learning resources provide realistic page-turning effects, intuitive navigation, and multimedia integration that enhance user engagement. Such features can increase students' motivation and improve their interaction with instructional content. Moreover, Flipbook technology supports the delivery of complex information through attractive visual and multimedia representations. Consequently, Flipbook-based e-modules have considerable potential to improve the quality of learning experiences in mathematics education.

Project-Based Learning is a student-centered instructional approach that emphasizes active participation, inquiry, collaboration, and authentic problem-solving. This learning model encourages students to investigate real-world problems and develop meaningful products as outcomes of the learning process (Lowell & Moore, 2020; Nilimaa, 2023; Rohm et al., 2021; Weng et al., 2022). Through project activities, students engage in planning, information gathering, analysis, implementation, and evaluation (Belwal et al., 2020; Hawari & Noor, 2020; Juuti et al., 2021). These learning experiences promote deeper conceptual understanding because students actively construct knowledge rather than passively receiving information. Project-Based Learning also supports the development of higher-order thinking skills, including critical thinking, creativity, and problem-solving (Chen et al., 2022; Hujjatusnaini et al., 2022; Loyens et al., 2023). Collaborative activities embedded within project work encourage students to exchange ideas and learn from one another. In addition, authentic projects provide opportunities for learners to connect theoretical knowledge with practical applications. The success of Project-Based Learning depends on the availability of instructional resources that can effectively guide students throughout the project process. Digital learning resources can strengthen the implementation of Project-Based Learning by providing flexible access to learning materials and project guidance. Therefore, integrating Project-Based Learning with digital technologies represents a promising strategy for improving learning outcomes in mathematics education.

Mathematical communication skills constitute a fundamental component of mathematics learning and play a significant role in students' cognitive development. These skills involve the ability to express mathematical ideas clearly and accurately through written, verbal, symbolic, and visual forms of communication. Effective mathematical communication enables students to explain reasoning processes, justify solutions, and interpret mathematical information presented by others. Communication also supports collaborative learning by facilitating discussion, argumentation, and knowledge sharing among learners (Baanqud et al., 2020; Darmawansah et al., 2022; Lin et al., 2020; Ng et al., 2022). Students with strong mathematical communication skills are generally more capable of constructing conceptual understanding and solving complex mathematical problems.

Furthermore, mathematical communication contributes to the development of critical thinking because students must evaluate and defend mathematical arguments. The ability to communicate mathematical ideas effectively is increasingly recognized as an essential competency in twenty-first-century education. However, many students continue to experience difficulties in articulating mathematical reasoning and presenting solutions systematically. These challenges highlight the need for instructional approaches that actively engage students in communicating mathematical ideas. Therefore, enhancing mathematical communication skills remains an important objective in mathematics education research and practice.

The integration of Flipbook-based e-modules and Project-Based Learning provides a theoretical foundation for improving mathematical communication skills within digital mathematics education. Flipbook technology offers interactive and multimedia-rich learning experiences that can support students' understanding of mathematical concepts. At the same time, Project-Based Learning provides authentic contexts that encourage students to discuss, explain, and communicate mathematical ideas during project activities (Chang et al., 2024; Cruz et al., 2022; Lazi et al., 2021; Rehman et al., 2024; Viro et al., 2020). The combination of these approaches creates opportunities for students to engage in meaningful learning experiences that involve both independent study and collaborative inquiry. Interactive digital content can facilitate conceptual understanding, while project activities promote communication and reflection. Students are encouraged to represent mathematical ideas using multiple forms of communication, including written explanations, diagrams, graphs, and mathematical symbols. Furthermore, project-based tasks require students to present findings, justify decisions, and evaluate the perspectives of others. Such activities align closely with the indicators of mathematical communication skills. The integration of digital technology and project-oriented learning may therefore provide a comprehensive framework for developing communication competencies in mathematics education. Consequently, the development and evaluation of a Flipbook-based Project-Based Learning e-module represents an important contribution to advancing digital mathematics education and enhancing students' mathematical communication skills.

METHOD

Research Design

This study employed a Research and Development (R&D) approach to develop and evaluate a Flipbook-based Project-Based Learning (PjBL) e-module designed to enhance students' mathematical communication skills. The development process followed the ADDIE instructional design model, which consists of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected because it provides a comprehensive framework for designing, developing, validating, and evaluating educational products. Through this model, the developed e-module was designed to integrate digital learning resources with Project-Based Learning activities. The research focused on producing a learning resource that met the criteria of validity, practicality, and effectiveness. The validity of the product referred to the appropriateness of its content, instructional design, and alignment with Project-Based Learning principles. Practicality referred to the ease of use and usability of the e-module from students' perspectives. Effectiveness referred to the ability of the e-module to improve students' mathematical communication skills during learning activities. The development process involved iterative revisions based on expert feedback and field-testing results. Therefore, the study not only produced an instructional product but also evaluated its educational quality and instructional impact.

Participant

The participants of this study were graduate students enrolled in the Digital Mathematics Education course in the Master's Program of Mathematics Education at Universitas Muhammadiyah Metro. A total of 16 students participated in the field implementation stage to evaluate the effectiveness of the developed e-module. These participants were selected because they were directly involved in learning activities related to digital mathematics education and regularly engaged in project-based assignments. Prior to the field implementation, a small-group trial was conducted involving 10 students to assess the practicality of the e-module. In addition, two expert validators participated in the validation process. One validator was responsible for evaluating the content and instructional aspects of the e-module, while the other evaluated the media design and visual presentation. The expert validators were selected based on their expertise in mathematics education and educational technology. Their evaluations provided important feedback regarding the quality and appropriateness of the developed product. The involvement of both experts and students ensured a comprehensive evaluation of the e-module from pedagogical and user perspectives. Consequently, the participants contributed valuable information to the validation, practicality, and effectiveness assessments conducted throughout the study.

Instrument

Data were collected using validation questionnaires, student response questionnaires, observation rubrics, and field notes. Expert validation questionnaires were used to assess the validity of the developed e-module. The content validation instrument evaluated the alignment of learning materials with course learning outcomes, the adequacy of supporting materials, and the consistency of instructional activities with Project-Based Learning characteristics. The media validation instrument assessed presentation quality, visual design, readability, layout organization, and graphical aspects of the e-module. To evaluate practicality, student response questionnaires were administered during the small-group trial. These questionnaires measured students' perceptions regarding the appearance, content presentation, usefulness, and ease of use of the e-module. The effectiveness of the e-module was evaluated through classroom implementation using observation rubrics designed to assess mathematical communication skills. Four indicators of mathematical communication were observed, namely mathematical writing, communication of mathematical ideas, mathematical representation, and the ability to analyze and evaluate others' opinions. The field implementation was conducted through classroom action research consisting of two cycles. The product was considered valid and practical when the average percentage score exceeded 60%, while effectiveness was determined by an improvement between cycles and an achievement score exceeding 75%.

Research Procedure

The research procedure followed the five stages of the ADDIE model. During the Analysis stage, instructional needs, student characteristics, and existing learning problems were identified through observations and discussions with lecturers and students. The Design stage involved preparing the e-module framework, organizing learning materials, designing Project-Based Learning activities, and developing validation instruments. During the Development stage, the Flipbook-based e-module was created and subsequently validated by content and media experts. Revisions were conducted based on expert suggestions and recommendations to improve the quality of the product. After revision, a small-group trial was conducted to evaluate the practicality of the e-module and obtain student feedback. The Implementation stage involved classroom field testing with 16 graduate students enrolled in the Digital Mathematics Education course. Learning activities were conducted using six Project-Based Learning phases, namely problem identification, project design, project development, project monitoring, product assessment, and reflection. During

implementation, students' mathematical communication skills were observed and evaluated across two classroom action research cycles. Finally, the Evaluation stage involved analyzing all collected data, reflecting on implementation outcomes, and conducting final revisions to ensure that the developed e-module met the criteria of validity, practicality, and effectiveness.

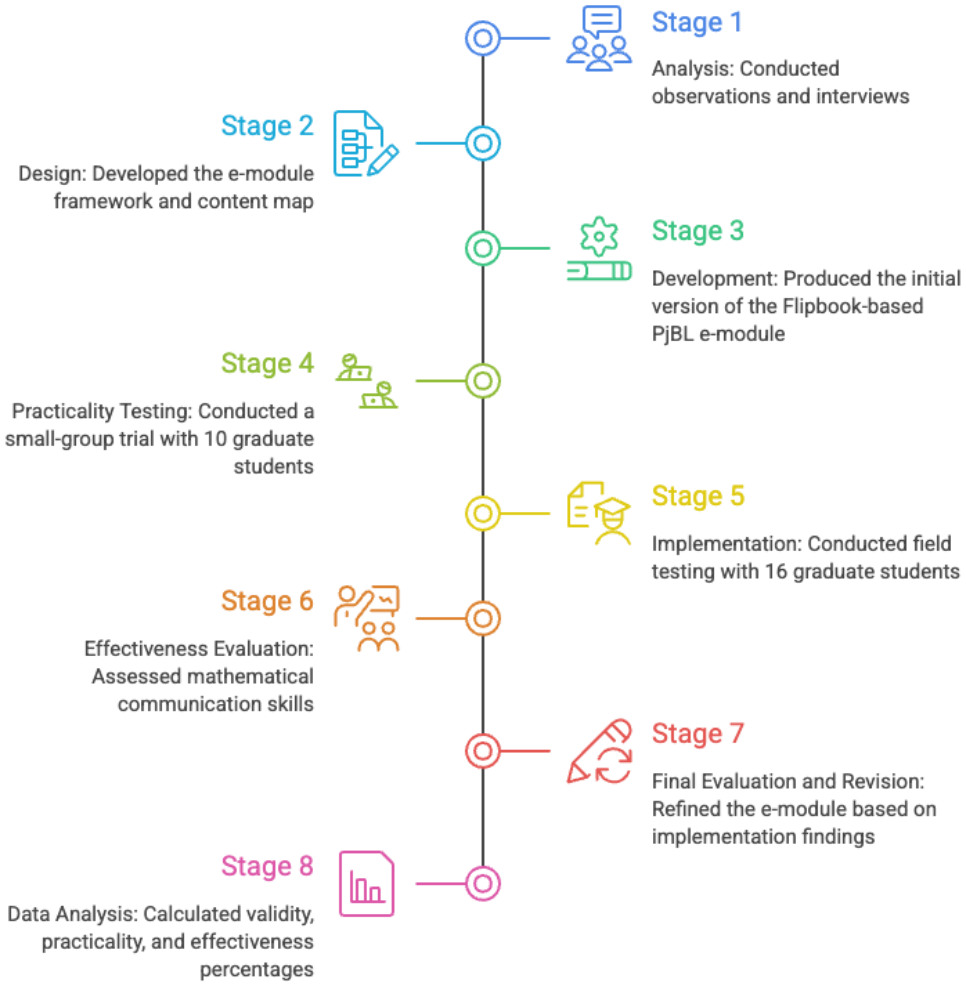


Figure 1. Research Method Flow

Data Analysis

The collected data were analyzed using descriptive quantitative and qualitative techniques. Quantitative data obtained from expert validation and student response questionnaires were analyzed using descriptive statistics in the form of percentages and mean scores. The validity score was calculated by determining the percentage of expert evaluations across all assessment indicators. Similarly, practicality scores were calculated based on students' responses to the developed e-module. These quantitative results were used to determine whether the product met the predetermined criteria for validity and practicality. Effectiveness data were analyzed by comparing students' mathematical communication performance across two implementation cycles. Improvements in communication skills were identified through percentage changes between the first and second cycles. Qualitative data obtained from observations and field notes were analyzed descriptively to provide additional explanations regarding students' learning experiences and interactions with the e-module. The qualitative findings were used to support and strengthen the

interpretation of quantitative results. Through the integration of quantitative and qualitative analyses, the study generated a comprehensive evaluation of the developed e-module.

RESULTS AND DISCUSSION

Results

Development of the Flipbook-Based Project-Based Learning E-Module

The development process resulted in a Flipbook-based Project-Based Learning (PjBL) e-module designed for the Digital Mathematics Education course. The product was developed through the five stages of the ADDIE model, namely Analysis, Design, Development, Implementation, and Evaluation. During the analysis stage, interviews with lecturers and students revealed that existing learning materials were limited to conventional modules, lacked interactive features, and provided insufficient opportunities for project-based activities. Furthermore, students experienced difficulties in transforming theoretical knowledge into tangible educational products. Based on these findings, a digital learning resource integrating Flipbook technology and Project-Based Learning was designed to address these instructional challenges. During the design stage, a comprehensive module framework and content structure were developed. The e-module incorporated six Project-Based Learning phases, namely problem identification, project design, project development, project monitoring, product assessment, and reflection. The developed module consisted of learning objectives, instructional materials, project assignments, self-assessment activities, and references. Subsequently, the module was converted into a Flipbook format to provide interactive navigation and multimedia-enhanced learning experiences.

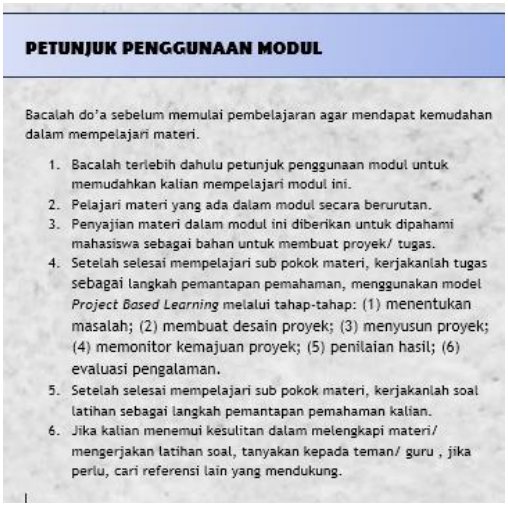
(a) (b)

Figure 2. E-Module Cover and Table of Contents

Figure 2 (a). Cover Page of the Developed Flipbook-Based PjBL E-Module

The figure presents the cover page of the Flipbook-based Project-Based Learning (PjBL) e-module developed for the Digital Mathematics Education course. The cover incorporates a modern visual design featuring images related to digital technology, virtual reality, global connectivity, and learning activities, which reflect the main themes of the module. The layout and color scheme were designed to enhance visual attractiveness and support students' engagement with the digital learning resource. The cover also provides essential information, including the module title, authors, publication year, and institutional affiliation, serving as the introductory interface of the developed e-module.

Figure 2 (b). Table of Contents of the Developed Flipbook-Based PjBL E-Module
The figure presents the table of contents of the Flipbook-based Project-Based Learning (PjBL) e-module developed for the Digital Mathematics Education course. The module is systematically organized into several sections, including the cover page, preface, table of contents, user guidelines, learning outcomes, and six instructional chapters. The learning materials cover key topics such as digital technology in education, digital learning strategies and prospects, management of digital technology in education, and digital learning applications. This structured organization provides learners with a clear learning pathway and facilitates navigation throughout the module. The arrangement of content is intended to support independent learning and guide students through project-based activities in a logical and sequential manner.



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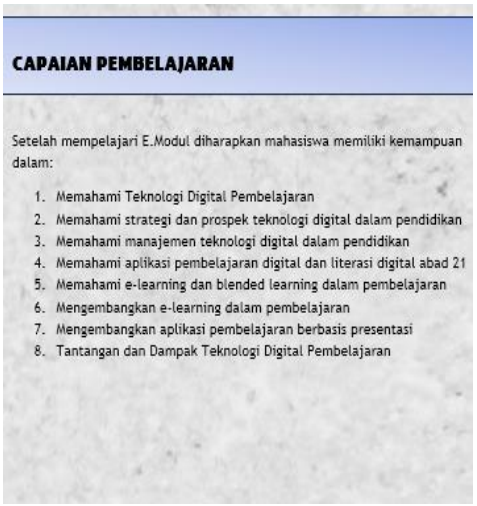

(d)

Figure 3. Display of Instructions for Use and Learning Outcomes

Figure 3 (a). User Guidelines of the Developed Flipbook-Based PjBL E-Module
The figure presents the user guidelines section of the Flipbook-based Project-Based Learning (PjBL) e-module. This section provides step-by-step instructions to help students use the module effectively and navigate the learning process independently. The guidelines encourage learners to study the materials sequentially, complete project-based assignments, and follow the six phases of Project-Based Learning, namely problem identification, project design, project development, project monitoring, product assessment, and reflection. In addition, students are advised to review supporting references when encountering difficulties in understanding the content. These instructions are intended to promote self-directed learning, active participation, and effective engagement with project-based activities throughout the course.

Figure 3 (b). Learning Outcomes of the Developed Flipbook-Based PjBL E-Module
The figure presents the learning outcomes section of the Flipbook-based Project-Based Learning (PjBL) e-module. This section outlines the competencies that students are expected to achieve after completing the learning activities. The learning outcomes include understanding digital technology in education, learning strategies and prospects of digital technology, management of digital technology in educational settings, digital learning applications, and twenty-first-century digital literacy. In addition, students are expected to develop digital learning e-content and design technology-based instructional media and presentation tools. The learning outcomes also emphasize students' understanding of the challenges and impacts of digital technology in education. These competencies provide a clear framework for learning activities and guide students toward achieving the objectives of the Digital Mathematics Education course.

(a) (b)

Figure 4. E-module Material Display

Figure 4 (a). Learning Material Section of the Developed Flipbook-Based PjBL E-Module
The figure presents a sample learning material page from the Flipbook-based Project-Based Learning (PjBL) e-module. This section discusses the topic *Strategies and Prospects of Digital Technology in Learning*, particularly focusing on digital learning platforms and their role in expanding access to education. The material provides theoretical explanations, contextual examples, and current educational perspectives related to the integration of digital technologies in teaching and learning. The content is organized systematically to facilitate students' understanding of key concepts before engaging in project-based activities. The clear layout, structured presentation, and readable format are intended to support independent learning and encourage students to critically explore the application of digital technologies in educational settings. Additionally, the material serves as a foundational resource for completing projects and enhancing students' understanding of digital mathematics education.

Figure 4 (b). Learning Material on Digital Technology Management in Education
The figure presents a learning material page from the Flipbook-based Project-Based Learning (PjBL) e-module that discusses *Digital Technology Management in Education*. This section introduces fundamental concepts of managing digital technologies within educational institutions, including planning, organizing, implementing, and evaluating digital learning processes. The material emphasizes the importance of effective management practices to ensure the successful integration of digital technologies into teaching and learning activities. In addition, it explains how digital learning systems can support educational administration, instructional delivery, and the achievement of learning objectives. The content is presented in a structured and accessible format to facilitate students' understanding of key management principles and their application in educational contexts. By linking theoretical concepts with practical examples, this section supports students in developing the knowledge required to manage and utilize digital technologies effectively in contemporary educational environments.

Validation Results

The validity of the developed e-module was evaluated by two expert validators, consisting of a content expert and a media expert. The content expert assessed the alignment of learning materials with course outcomes and Project-Based Learning principles, while the media expert evaluated presentation quality, graphical design, and usability.

Table 1. Expert Validation Results

Validation Aspect	Percentage (%)	Category
Content Validity	80	Valid
Media Validity	82	Very Valid
Average	81	Very Valid

The results indicate that the developed e-module achieved an overall validity score of 81%, which falls within the very valid category. Although the module was considered suitable for implementation, several revisions were recommended by the validators. The primary revisions included improving user instructions based on Project-Based Learning phases, simplifying language usage, enhancing graphical consistency, improving image quality, and adding project implementation guidelines. After revision, the validators confirmed that the e-module met the required quality standards for field implementation.

Table 2. Summary of Expert Recommendations

Aspect	Recommendation	Revision Implemented	Aspect
User Guidelines	Align with PjBL phases	Revised according to six PjBL phases	User Guidelines
Language	Improve clarity and readability	Simplified instructional language	Language
Project Tasks	Add project instructions	Project guidelines incorporated	Project Tasks
Visual Design	Improve color contrast	Color scheme revised	Visual Design
Graphics	Enhance image quality	Images redesigned	Graphics

Practicality Results

The practicality of the e-module was evaluated through a small-group trial involving ten graduate students. Students were asked to use the e-module and complete a response questionnaire covering appearance, content presentation, and usefulness.

Table 3. Practicality Evaluation Results

Aspect	Percentage (%)
Appearance	86.2
Content Presentation	84.8
Usefulness	86.1
Average	85.7

The average practicality score reached 85.7%, indicating that the e-module was highly practical. Students reported that the module was attractive, easy to navigate, and useful for supporting independent learning. They also indicated that the project-based activities helped them connect theoretical concepts with real-world applications in educational settings. These findings suggest that the developed e-module can be effectively used as a learning resource in digital mathematics education.

Effectiveness Results

The effectiveness of the developed e-module was evaluated through field implementation involving sixteen graduate students. Mathematical communication skills were assessed through two classroom action research cycles. Four indicators were evaluated, including mathematical writing, communication of ideas, mathematical representation, and critical evaluation of others' arguments.

Table 4. Mathematical Communication Skills Across Cycles

Cycle	Percentage (%)	Category
Cycle I	74	Moderate
Cycle II	82	High
Improvement	+8	-

The results demonstrated an increase in students' mathematical communication skills from 74% in Cycle I to 82% in Cycle II, representing an improvement of 8%. This improvement exceeded the predetermined effectiveness criterion of 75%.

Cycle I (74%) → Cycle II (82%)

Field observations further revealed that students became more active during discussions, demonstrated greater confidence in presenting mathematical ideas, and were better able to justify their reasoning. Students also showed improved abilities in representing mathematical concepts through written explanations, diagrams, and graphical representations. These findings indicate that the integration of Flipbook technology and Project-Based Learning effectively supported the development of mathematical communication skills.

Product Characteristics

The final product was a Flipbook-based Project-Based Learning e-module accessible through computers and Android devices. The module consisted of introductory sections, learning materials, project activities, summaries, and references. The instructional content covered six major topics related to Digital Mathematics Education. The integration of multimedia content and project-based activities provided students with opportunities for independent learning, collaborative inquiry, and authentic problem-solving. The final product was determined to be valid, practical, and effective for enhancing mathematical communication skills in digital mathematics education.

Discussion

The findings indicate that the developed Flipbook-based Project-Based Learning (PjBL) e-module achieved a high level of validity, with an average validation score of 81%, suggesting that the instructional content, media design, and learning activities were appropriately aligned with the intended learning outcomes. The positive validation results demonstrate that the integration of Flipbook technology and Project-Based Learning principles produced a coherent instructional product suitable for use in digital mathematics education (Hossein-Mohand et al., 2021). The validators emphasized the importance of aligning project activities with learning objectives and ensuring that instructional guidance was sufficiently clear for independent learning. These findings support the view that the quality of digital learning resources depends not only on technological features but also on the pedagogical design embedded within the instructional materials (Alberola-Mulet et al., 2021; Gameil & Al-Abdullatif, 2023; Konstantinidou & Nisiforou, 2022; Rice & Ortiz, 2021; Timotheou et al., 2023). The revision process contributed significantly to improving the overall quality of the e-module by refining language, strengthening project guidelines, and improving visual presentation. The results are consistent with previous studies reporting that well-designed e-modules can effectively support learning when content organization, instructional strategies, and technological features are integrated systematically. Earlier research on digital modules has similarly highlighted the importance of content validity and instructional alignment in determining the effectiveness of technology-enhanced learning resources (Choi-Lundberg et al., 2023; Smith et al., 2021; Tsipa-Booi & Ntlabathi, 2026; van Haastrecht et al., 2024). The current study extends these findings by demonstrating that the incorporation of Project-Based Learning elements into a Flipbook-based environment can produce a valid instructional resource that addresses both technological and pedagogical requirements. This result suggests that instructional quality remains a critical determinant of successful digital learning implementation. Therefore, careful attention to content design and learning structure is essential when developing digital learning materials for mathematics education.

The practicality evaluation further demonstrated that students perceived the developed e-module as highly usable, with an average practicality score of 85.7%. Students reported that the

module was attractive, easy to navigate, and helpful in supporting independent learning activities. The interactive features embedded within the Flipbook format appeared to enhance students' engagement with the learning materials and encouraged them to explore content more actively. These findings align with previous studies indicating that multimedia-rich digital learning environments can improve learner motivation and satisfaction (Hidayati & Slamet, 2025; Staneviciene & Žekienė, 2025). Unlike conventional printed modules, the Flipbook format provides a more dynamic learning experience through the integration of text, images, and interactive navigation. Students also appreciated the flexibility of accessing the module through different devices, which facilitated learning beyond classroom settings. Furthermore, the project-based tasks encouraged learners to apply theoretical knowledge to authentic educational situations, thereby increasing the perceived relevance of the learning experience. Similar findings have been reported in studies examining the use of digital modules and project-oriented learning approaches, where students demonstrated greater engagement and autonomy during learning activities (Gupta, 2022; Naseer et al., 2025; Zen et al., 2022). However, the present study contributes additional evidence by showing that the combination of Flipbook technology and Project-Based Learning can simultaneously support usability and instructional effectiveness. These results suggest that well-designed digital resources can promote student-centered learning by creating flexible and engaging learning environments.

The effectiveness analysis revealed that students' mathematical communication skills increased from 74% in the first implementation cycle to 82% in the second cycle, representing an improvement of 8%. This finding indicates that the developed e-module successfully facilitated the development of students' abilities to express mathematical ideas, communicate reasoning processes, and evaluate mathematical arguments. One possible explanation for this improvement is that Project-Based Learning requires students to continuously discuss, present, justify, and reflect upon their work throughout the project process. Such activities naturally create opportunities for communication and collaborative knowledge construction. The iterative nature of project development also encourages students to refine their explanations and improve the clarity of their mathematical reasoning. Previous studies have consistently reported that Project-Based Learning contributes to the development of higher-order thinking skills, including critical thinking and problem solving (Loyens et al., 2023). The present findings extend this body of knowledge by demonstrating that Project-Based Learning can also serve as an effective approach for improving mathematical communication skills (Owens & Hite, 2022; Rehman et al., 2024; Viro et al., 2020). Furthermore, the interactive learning environment created through the Flipbook-based module provided students with structured guidance and learning support throughout the project activities. This combination of technological and pedagogical support appears to have facilitated deeper engagement with mathematical concepts and communication processes. Consequently, the findings reinforce the potential of Project-Based Learning as a powerful instructional approach within digital mathematics education.

The improvement observed in mathematical communication skills can also be interpreted through the theoretical relationship between communication, representation, and conceptual understanding in mathematics learning. Mathematical communication requires students to transform abstract ideas into meaningful written, verbal, symbolic, and visual representations. The developed e-module provided opportunities for students to engage with mathematical concepts through multiple forms of representation, including textual explanations, project reports, diagrams, and presentations. These activities encouraged students to articulate their reasoning and communicate their understanding more explicitly. Previous research has suggested that communication plays a central role in supporting conceptual development because learners construct knowledge through interaction and dialogue. In the context of Project-Based Learning, communication becomes an integral component of the learning process because students must

collaborate, negotiate meaning, and present project outcomes (Hussein, 2021; Owens & Hite, 2022). The findings of this study are consistent with those theoretical perspectives, as students demonstrated improved communication performance after engaging in project-based learning activities supported by digital technology (Al-Bahadli et al., 2023; Ngereja et al., 2020; Owens & Hite, 2022; Q. Zhang & Lin, 2026). Moreover, the ability to communicate mathematical ideas effectively is increasingly recognized as an important competency in contemporary education and professional practice. The current results therefore provide empirical support for the integration of communication-oriented activities within digital mathematics learning environments. By promoting both conceptual understanding and communication skills, the developed e-module contributes to more comprehensive mathematics learning experiences.

The overall findings suggest that the integration of Flipbook technology and Project-Based Learning offers a promising instructional framework for digital mathematics education. While previous studies have examined digital modules, Flipbook technology, and Project-Based Learning separately, the present study demonstrates the educational value of combining these elements within a single instructional product. The validity, practicality, and effectiveness results collectively indicate that the developed e-module successfully addressed the instructional challenges identified during the needs analysis stage. In particular, the e-module provided students with structured project guidance, interactive learning materials, and opportunities for meaningful communication. The study therefore contributes to the growing literature on technology-enhanced mathematics education by providing empirical evidence regarding the development and evaluation of innovative digital learning resources. Furthermore, the findings highlight the importance of integrating pedagogical models and technological tools rather than focusing exclusively on technological innovation. Educational technologies are most effective when they are supported by instructional approaches that actively engage learners in meaningful learning activities. The positive outcomes observed in this study suggest that future instructional innovations should continue to emphasize the integration of active learning strategies and digital technologies. Such integration has the potential to support not only academic achievement but also the development of essential twenty-first-century competencies. Therefore, the developed Flipbook-based Project-Based Learning e-module may serve as an effective model for future digital learning innovations in mathematics education.

Implications

The findings of this study have important implications for both mathematics education practice and the development of technology-enhanced learning resources in higher education. The successful development of a valid, practical, and effective Flipbook-based Project-Based Learning e-module demonstrates that the integration of digital technology and active learning pedagogy can provide meaningful support for the development of mathematical communication skills. From a pedagogical perspective, the study highlights the importance of designing learning environments that encourage students to actively construct knowledge, communicate ideas, and engage in authentic problem-solving activities rather than merely receiving information passively. The integration of Project-Based Learning within a digital module provides opportunities for students to connect theoretical concepts with practical applications, thereby fostering deeper conceptual understanding and more effective communication of mathematical reasoning. The findings also suggest that digital learning resources should be designed not only to deliver content but also to facilitate interaction, reflection, collaboration, and communication throughout the learning process. For lecturers and instructional designers, the developed e-module may serve as a model for creating student-centered digital learning materials that support both cognitive and communication-related learning outcomes. The positive results obtained in this study further indicate that Flipbook

technology can be utilized as an accessible and flexible platform for delivering interactive learning experiences in mathematics education. At the institutional level, the implementation of similar digital learning innovations may contribute to the improvement of instructional quality and support the broader integration of digital technologies within higher education curricula. The study also reinforces the growing recognition that mathematical communication should be positioned as a core learning outcome alongside conceptual understanding and problem-solving skills. Furthermore, the integration of communication-oriented activities within project-based digital learning environments may help prepare students for professional contexts that require collaboration, critical thinking, and effective communication. The findings therefore provide empirical support for expanding the use of project-based digital learning resources across other mathematics-related courses and educational settings. Ultimately, this study contributes to the advancement of digital mathematics education by offering a practical framework for integrating technology, project-based pedagogy, and mathematical communication into a coherent and effective instructional approach.

Limitations and Suggestions for Future Research

Despite the positive findings, several limitations should be acknowledged when interpreting the results of this study. First, the research involved a relatively small sample consisting of only sixteen graduate students from a single mathematics education program, which may limit the generalizability of the findings to broader educational contexts. Second, the effectiveness of the developed e-module was evaluated through classroom action research involving two implementation cycles rather than through an experimental or quasi-experimental design that could provide stronger evidence of causal relationships. Third, the study focused exclusively on mathematical communication skills and did not examine other important learning outcomes such as critical thinking, creativity, problem-solving ability, digital literacy, or learning achievement. Fourth, the implementation period was relatively short and therefore did not allow for the investigation of the long-term effects of the e-module on students' learning development. Fifth, the practicality assessment relied primarily on students' self-reported perceptions, which may be influenced by personal preferences and response bias. Sixth, the developed e-module was implemented only within the Digital Mathematics Education course, making it difficult to determine its applicability across different mathematics subjects and educational levels. Future studies are therefore encouraged to involve larger and more diverse samples drawn from multiple institutions to improve the external validity of the findings. Researchers may also employ experimental or quasi-experimental designs to compare the effectiveness of Flipbook-based Project-Based Learning e-modules with other instructional approaches. In addition, future investigations should examine the impact of the developed e-module on a wider range of cognitive, affective, and technological competencies. Longitudinal studies are recommended to evaluate the sustainability of learning outcomes and communication skills over extended periods of instruction. Further research may also explore the integration of advanced technologies, such as artificial intelligence, adaptive learning systems, or learning analytics, to enhance the functionality of digital modules. Finally, comparative studies across educational contexts, subject areas, and student characteristics would provide deeper insights into the broader educational potential of Flipbook-based Project-Based Learning e-modules in digital mathematics education.

CONCLUSION

This study successfully developed and evaluated a Flipbook-based Project-Based Learning (PjBL) e-module for the Digital Mathematics Education course using the ADDIE development model. The development process systematically integrated digital learning resources, multimedia features, and project-oriented learning activities to create an instructional product that supports meaningful

learning experiences. The results demonstrated that the developed e-module achieved a validity score of 81%, indicating that the content, instructional design, and media components were appropriate for educational use. The practicality evaluation further revealed that the e-module was highly practical, as reflected by a student response score of 85.7%, suggesting that the product was easy to use, engaging, and beneficial for learning activities. The implementation results also confirmed that the developed e-module was effective in enhancing students' mathematical communication skills. Students' communication performance improved from 74% in the first cycle to 82% in the second cycle, indicating a meaningful increase in their ability to express mathematical ideas, communicate reasoning processes, use mathematical representations, and evaluate the arguments of others. These findings suggest that the integration of Flipbook technology and Project-Based Learning creates a learning environment that encourages active participation, independent learning, collaboration, and reflective thinking. The study further demonstrates that mathematical communication skills can be effectively supported through digital learning resources that combine interactive content with authentic project activities. In addition, the findings provide empirical evidence that technology-enhanced instructional materials can contribute not only to knowledge acquisition but also to the development of essential communication competencies in mathematics education. The developed e-module therefore represents a practical instructional innovation that responds to the growing demand for digital and student-centered learning approaches in higher education. The study also contributes to the literature on digital mathematics education by providing evidence regarding the educational value of integrating project-based pedagogy with interactive digital learning media. Overall, the Flipbook-based Project-Based Learning e-module can be considered a valid, practical, and effective learning resource for improving mathematical communication skills and supporting the implementation of digital mathematics education in higher education settings.

AUTHOR CONTRIBUTIONS STATEMENT

Sutrisni Andayani conceptualized and designed the research framework, led the development of the Flipbook-based Project-Based Learning e-module, and coordinated the overall project implementation. Dwi Rahmawati contributed to the design of instructional materials, prepared the Project-Based Learning activities, and conducted the validation and practicality assessments with students. Rahmat Bustanul Anwar oversaw the data collection process, performed quantitative and qualitative data analyses, and drafted the results and discussion sections. All authors collaborated in revising the manuscript, critically reviewed the final version, and approved the submission of the article. Each author agrees to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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