Development of Integrated Interactive E-Modules for Problem Based Learning in Mathematics Learning for Grade XI Phase F of Senior High School

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Abstract *: The transformation of learning under the Independent Curriculum requires digital teaching materials that support active learning and strengthen mathematical problem-solving skills. However, matrix instruction remains dominated by conventional materials, making abstract concepts difficult for students to understand. This study aims to develop a valid, practical, and effective interactive e-module integrated with Problem-Based Learning (PBL) for Grade XI Phase F students. The study employed a Research and Development approach using the 4-D model, comprising define, design, develop, and disseminate stages. Data were collected through validation sheets, practicality questionnaires, and learning outcome tests. The results showed that the e-module achieved 92.68% validity, categorised as very valid, and 98.75% practicality, categorised as very practical. Its effectiveness was demonstrated by an increase in the average score from 31.67 to 92.92, with an N-Gain value of 0.90 in the high category. These findings indicate that the PBL-integrated e-module effectively improves students' understanding of matrix concepts and mathematical problem-solving skills while supporting the Independent Curriculum.*

Keywords : *Interactive E-Module; Mathematical Problem Solving Skills; Matrix; Problem-Based Learning; Secondary Mathematics Education.*

Abstrak: Transformasi pembelajaran dalam Kurikulum Merdeka membutuhkan bahan ajar digital yang mendukung pembelajaran aktif dan memperkuat keterampilan pemecahan masalah matematis. Namun, pembelajaran matriks masih didominasi oleh bahan ajar konvensional sehingga konsep-konsep abstrak sulit dipahami oleh peserta didik. Penelitian ini bertujuan mengembangkan e-modul interaktif terintegrasi *Problem-Based Learning* (PBL) untuk peserta didik kelas XI Fase F yang valid, praktis, dan efektif. Penelitian menggunakan pendekatan *Research and Development* dengan model 4-D yang meliputi tahap *define, design, develop,* dan *disseminate*. Data dikumpulkan melalui lembar validasi, angket kepraktisan, dan tes hasil belajar. Hasil penelitian menunjukkan bahwa e-modul mencapai validitas sebesar 92,68% dengan kategori sangat valid dan kepraktisan sebesar 98,75% dengan kategori sangat praktis. Efektivitasnya ditunjukkan oleh peningkatan skor rata-rata dari 31,67 menjadi 92,92 dengan nilai N-Gain sebesar 0,90 dalam kategori tinggi. Temuan ini menunjukkan bahwa e-modul terintegrasi PBL efektif meningkatkan pemahaman konsep matriks dan

keterampilan pemecahan masalah matematis serta mendukung implementasi Kurikulum Merdeka.

Kata kunci: E-Modul Interaktif; Keterampilan Pemecahan Masalah Matematis; Matriks; *Problem-Based Learning*; Pendidikan Matematika Sekolah Menengah.

INTRODUCTION

Problem-solving ability is one of the key competencies expected to develop through mathematics learning (Narh-Kert et al., 2025; Sari et al., 2025) . This competency not only reflects the ability to solve mathematical problems but also demonstrates the skills to analyze information, connect various concepts, and determine logical solution strategies (N. Christi & Rajiman, 2023; Nguyen et al., 2024) . However, the learning process in schools is still dominated by activities oriented towards procedural solutions, so students are more accustomed to following solution examples rather than building conceptual understanding independently.

A needs analysis conducted at SMA Pertiwi 1 Padang revealed that mathematics learning still relies on textbooks and worksheets as the primary learning resources. The use of digital media has not been optimal, even though most students have devices that support technology-based learning. This situation leaves less space in the learning process for students to explore concepts through investigation, discussion, and contextual problem-solving. This challenge is increasingly apparent in matrix material, which is abstract and requires visualization and a more interactive learning experience for a comprehensive understanding of the concepts (Liu et al., 1999; Van Der Meij et al., 2017; Schoenherr & Schukajlow, 2024).

The development of digital teaching materials provides opportunities for more flexible and meaningful learning experiences. Interactive e-modules integrate text, images, videos, animations, and interactive exercises into a single learning medium, enabling students to learn independently at their own pace. However, the effectiveness of e-modules is determined not only by the quality of the multimedia but also by the learning design that guides students in building knowledge through higher-order thinking activities (Abuhassna & Alnawajha, 2023; Nurrijal et al., 2023; Yumiati et al., 2025).

Various studies report that interactive e-modules increase student motivation, learning outcomes, and engagement. Other research also shows that implementing *Problem-Based Learning* (PBL) effectively develops critical thinking and mathematical problem-solving skills (Hasan, 2024). However, studies that fully integrate PBL syntax into interactive e-modules for matrix materials are still relatively limited. Most studies focus on media development or solely on evaluating the product's validity and practicality, so the contribution of instructional design to students' learning experiences has been understudied.

This study offers a different approach by developing an interactive e-module that integrates the full syntax of *Problem-Based Learning* into each learning activity. The e-module is designed using an interactive flipbook platform, combining contextual problems, multimedia, exercises, reflection, and evaluation as a unified learning experience. The design was developed based on an analysis of the needs of Grade XI Phase F students, the characteristics of matrix materials, and the implementation of the Independent Curriculum. This not only produces digital learning media but also provides a learning plan that supports the development of mathematical problem-solving skills (Lu & Xie, 2024; Zhang et al., 2024) .

This study aims to develop an integrated interactive *Problem-Based Learning* e-module that meets the criteria of validity, practicality, and effectiveness for mathematics learning in Grade XI Phase F of senior high school. The results of the study are expected to contribute to the development of digital teaching materials that integrate technology and learning strategies more systematically, as well as being an alternative for teachers in creating more interactive, contextual, and student-centered mathematics learning.

METODE PENELITIAN

This research is a research and development (*R&D*) that aims to produce an integrated interactive e-module *for Problem-Based Learning* (PBL) in mathematics learning for grade XI Phase

F of high school. The product development adapts the Four-D (4-D) model proposed by Thiagarajan et al. (1974) , including *the define*, *design*, *develop*, and *disseminate stages*. This model was chosen because it provides a systematic set of stages for producing learning products, including needs analysis, design, development, validation, and implementation. The *define stage* focuses on identifying learning needs through curriculum analysis, student characteristics, matrix material characteristics, and learning conditions in schools. The results of the analysis serve as the basis for determining learning objectives, preparing materials, and specifying the developed e-module. (Branch, 2009; Hase & Kuhl, 2024; Senadheera et al., 2024).

The design phase includes the e-module structure, research instrument development, problem-based learning activity design, and interface development using an interactive flipbook platform. The development phase includes product validation by subject-matter, media, and language experts, followed by revisions based on the validators' input. The revised product is then tested with teachers and students to gather data on the e-module's practicality and effectiveness. The dissemination phase is carried out through limited implementation in research schools as a form of product dissemination.

The research was conducted at SMA Pertiwi 1 Padang with research subjects including validators, mathematics teachers, and grade XI Phase F students. The validators consisted of materials experts, media experts, and linguists who were tasked with assessing the feasibility of the e-module's content, presentation, display, and linguistic aspects. The practicality test involved subject teachers and students as product users, while the effectiveness test was conducted on students who used the e-module in the learning process. Research data were collected using validation sheets, practicality questionnaires, and learning outcome tests. The validation sheet was used to assess the product's feasibility across content, learning design, media, and language. The practicality questionnaire was used to obtain teacher and student responses regarding ease of use, attractiveness of the display, clarity of the material, and the usefulness of the e-module in learning. The learning outcome test was used to measure the effectiveness of the e-module in supporting the achievement of learning objectives for matrix material (X. Wei et al., 2021; Valverde-Berrocoso et al., 2022). Data were analyzed quantitatively and descriptively. Validity and practicality scores were converted to percentages and interpreted according to predetermined eligibility categories. The effectiveness of the e-module was analyzed based on the percentage of students' learning outcomes achieved after using the product. An e-module is deemed to meet quality criteria if it is categorized as valid based on expert assessment, practical based on user responses, and effective based on student learning outcomes.

RESULTS AND DISCUSSION

Needs Analysis as the Basis for E-Module Development

The development of an integrated interactive e-module using *Problem-Based Learning* (PBL) begins with a needs analysis to obtain an overview of the conditions for mathematics learning, student characteristics, curriculum demands, and the need for digital teaching materials. This stage serves as the basis for determining the specifications of the product being developed to address learning challenges in the field. The analysis was conducted through classroom observations, interviews with mathematics teachers, questionnaires distributed to students, and analysis of learning documents used at SMA Pertiwi 1 Padang.

Observations show that textbooks and student worksheets still dominate the learning process as the primary learning resources. Teachers have utilized presentation media in several meetings, but their use remains limited to delivering material, resulting in limited student interaction in building knowledge. Learning activities are predominantly focused on solving examples and routine exercises, while opportunities for students to identify problems, discuss them, and discover concepts independently remain limited.

This situation is reinforced by interviews with teachers, which indicate that matrices are one of the subjects that often cause difficulties for students. This difficulty is caused not only by the abstract nature of the material but also by students' tendency to memorize problem-solving procedures without understanding the relationships among concepts. The impact is evident when

students face problems in contexts different from the examples provided by the teacher. This situation indicates that learning still requires teaching materials that connect mathematical concepts to real-world problems, enabling students to build a more meaningful understanding.

The results of the needs analysis indicate that the development of e-modules is not merely a response to technological developments but rather an effort to address learning needs that are not yet fully met by available teaching materials. This analysis also demonstrates that the successful implementation of digital teaching materials is largely determined by their suitability to student characteristics, curriculum demands, and the learning strategies used. These findings form the basis for designing interactive e-modules that are not only feasible to use but also capable of creating a more active, contextual learning experience, and oriented towards developing mathematical problem-solving skills.

Table 1. Summary of Needs Analysis Results

Analysis Aspects	Key Findings	Implications for E-Module Development
Learning	Teacher-centered, dominated by textbooks and LKPD	Developing interactive digital teaching materials
Learners	Have a smartphone, be used to using technology	E-modules can be accessed independently via digital devices
Material	Matrix material is abstract and difficult to understand	Add visualizations, animations, and contextual examples
Curriculum	The Independent Curriculum emphasizes active learning	Integrating Problem Based Learning syntax
Teacher Needs	Need media that is attractive and easy to use	Developing e-modules that are practical and easy to implement

A needs analysis revealed a gap between the learning characteristics expected in the Independent Curriculum and classroom learning practices. On the one hand, students have adequate technological readiness; on the other hand, the teaching materials used remain conventional and fail to optimize this potential (Khairul Anshari et al., 2024; Santosa et al., 2024). This situation formed the basis for the development of interactive e-modules that integrate a Problem-Based Learning approach , enabling technology to function not only as a medium for conveying information but also as a means of building meaningful learning experiences.

Characteristics of Integrated Interactive E-Modules with Problem Based Learning

The developed e-module was designed based on the results of an analysis of student needs, the characteristics of the matrix material, and the demands of the Independent Curriculum. The product was developed using Flip PDF Professional, integrating text, images, learning videos, interactive exercises, and evaluations into a single medium accessible via computer or smartphone. The e-module structure includes user instructions, learning outcomes, concept maps, materials, *Problem-Based Learning* (PBL) activities, exercises, and evaluations, along with several key images.

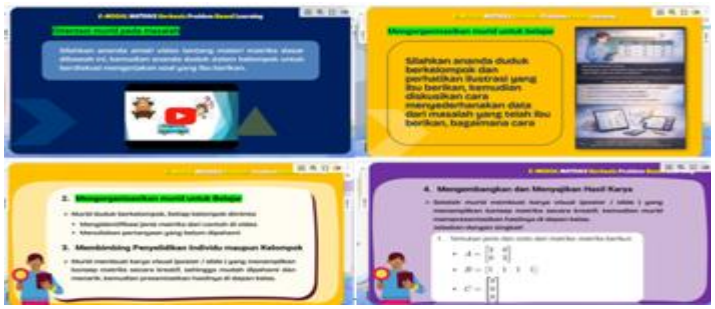

Figure 1. E-Module Components

One of the main characteristics of e-modules is the integration of PBL syntax into each learning activity. Students not only learn matrix concepts but are also guided to identify problems,

explore information, discuss alternative solutions, and reflect on the results. The integration of multimedia and problem-based activities is designed to help students understand abstract concepts through more contextual and interactive learning experiences.

Table 2. Characteristics of Integrated PBL Interactive E-Modules.

Component	Implementation in E-Module
Material	Arranged according to the learning outcomes of the matrix material
Multimedia	Text, images, videos, animations, and interactive exercises
Learning model	Integrating *Problem Based Learning syntax*
Evaluation	Problem-solving based formative exercises and tests
Accessibility	Can be used via computer or smartphone

These characteristics indicate that the developed e-module functions not only as a digital medium but also as a learning tool that integrates technology with problem-based learning strategies. This design is expected to increase student engagement, facilitate understanding of matrix concepts, and support the development of mathematical problem-solving skills.

E-Module Validity

The e-module validity process aims to ensure that the developed product meets the eligibility standards for content, media design, and language before being implemented in learning. The validation process is conducted by three validators: a material expert, a media expert, and a language expert. The assessment focuses on the suitability of the material for learning outcomes, the quality of the media presentation, and the use of communicative language appropriate to learners' characteristics.

Table 3. Validation Results of Integrated PBL Interactive E-Module

Validation Aspects	Percentage (%)
Subject matter expert	85.19
Media expert	92.86
Linguist	100.00
Average	92.68

The high validity of the e-module (92.68%) indicates that the developed product has met the eligibility standards in terms of the material, media, and language aspects. This finding indicates that integrating Problem-Based *Learning syntax* with interactive multimedia features successfully produces teaching materials that not only meet curriculum demands but also support more meaningful learning. Although there are still some minor improvements based on validator input, the revisions are technical and do not affect the product's substance. Thus, the e-module is considered to have a strong pedagogical and technical foundation, making it suitable for implementation at the practicality testing stage.

E-Module Practicality

After being declared valid, the interactive e-module, integrated with *Problem-Based Learning* (PBL), was tested to assess its practicality in supporting mathematics learning. The practicality test involved teachers and students and assessed the e-module's ease of use, efficiency, appeal, and usefulness. The results of the practicality test are presented in Table 4.

Table 4. Practicality Level of Integrated PBL Interactive E-Modules

Practicality Aspect	Assessed Indicators	Percentage (%)	Category	Key Findings
Ease of use	Ease of operating menus, navigation, and e-module features	100.00	Very Practical	The e-module is easy to use without requiring intensive assistance.

Learning efficiency	Ease of following the learning flow and managing study time	98.44	Very Practical	Learning activities take place more systematically and efficiently.
Appearance appeal	Interface design, illustrations, colors, videos, and animations	98.75	Very Practical	Multimedia increases students' interest during learning.
Benefits of learning	Clarity of material, ease of understanding concepts, and usefulness of e-modules	97.81	Very Practical	E-modules help students understand matrix material through problem-based activities.
Average Practicality	Overall assessment aspects	98.75	Very Practical	The e-module is considered easy to use and supports mathematics learning effectively.

The practicality test results showed that the e-module obtained an average percentage of 98.75%, categorized as very practical, indicating that the product can be used easily by both teachers and students. The high level of practicality indicates that the e-module design is in accordance with user needs, both technically and pedagogically. The ease-of-use aspect received the highest rating. This finding indicates that the menu structure, navigation, and instructions for use are arranged simply so that students can access each section of the e-module independently. This convenience is an important factor in supporting technology-based learning because it allows students to focus more on the process of understanding concepts rather than learning how to operate the media (Furqanisah & Arifin, 2024).

The display's attractiveness also earned it a place in the very practical category. The integration of text, images, videos, animations, and interactive exercises provides a more engaging learning experience than using conventional teaching materials. Multimedia presentations not only increase motivation to learn but also help visualize abstract concepts in the matrix material, making them easier to understand. The learning benefits aspect shows that e-modules can support a more active learning process through the integration of Problem-Based Learning syntax. The presentation of contextual problems, investigative activities, exercises, and reflections encourage students to build conceptual understanding gradually. These conditions indicate that e-modules are not only practical to use but also provide a learning experience that aligns with the characteristics of learning in the Independent Curriculum.

Effectiveness of E-Modules and Their Implications

The effectiveness of the e-module was evaluated by assessing improvements in student learning outcomes after using the interactive e-module integrated with *Problem-Based Learning* (PBL) on matrix material. Measurements were conducted through *pretests* and *posttests , then analyzed using normalized gain (N-gain)* values . A summary of the effectiveness test results is presented in Table 5.

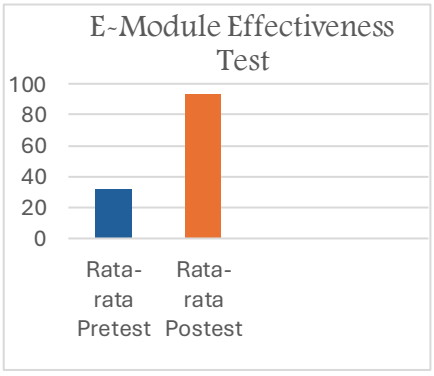

Figure 1. Results of the E-Module Effectiveness Test

The test results showed a significant improvement in learning outcomes after students used the e-module. The average score increased from 31.67 on the pretest to 92.92 on the posttest, with an N-gain of 0.90, which falls in the high category. These findings indicate that the e-module is effective in helping students understand matrix concepts and improve their mathematical problem-solving abilities (Hendriko et al., 2024; Maghfiroh et al., 2024). These improved learning outcomes are supported by the implementation of Problem-Based Learning syntax , which encourages students to actively engage in identifying problems, exploring information, developing problem-solving strategies, and reflecting on their learning outcomes. The integration of multimedia, including videos, illustrations, and interactive exercises, also helps visualize abstract concepts, making the material easier to understand. Overall, the research results show that the developed e-module meets three key product quality indicators: validity, practicality, and effectiveness. These findings indicate that integrating problem-based learning with interactive multimedia can create a more meaningful learning experience and support the implementation of student-centered mathematics learning.

Discussion

The results of the study indicate that the interactive e-module, integrated with Problem-Based Learning (PBL), meets three main indicators of product quality: validity, practicality, and effectiveness. These findings indicate that the development of the e-module not only produces suitable teaching materials but also optimally supports the mathematics learning process. The integration of materials, interactive multimedia, and PBL syntax provides a more structured learning experience, enabling students not only to understand concepts procedurally but also to relate them to contextual problem-solving (Harianto & I Gde Wawan Sudatha, 2024; Wasi'ah & Cahyono, 2025). The high level of validity indicates that the e-module has met the eligibility standards for content, media design, and language. The material's alignment with learning outcomes and the presentation of activities that follow PBL syntax enable students to build conceptual understanding gradually. Furthermore, the use of interactive multimedia, including images, videos, and problem-based exercises, strengthens the representation of abstract concepts, making the matrix material easier to understand (Putra et al., 2024; H. Wei et al., 2024). These findings demonstrate that the quality of digital teaching materials is determined by the integration of learning design, technology, and material characteristics, not solely by visual appearance.

The very high level of practicality indicates that e-modules are easy to implement in learning. Ease of navigation, systematic presentation of materials, and integration of problem-based activities allow teachers and students to use e-modules without experiencing significant obstacles. This condition indicates that the development process, which began with a needs analysis, successfully produced a product that meets user characteristics. Thus, e-modules function not only as digital media but also as learning tools that facilitate active student engagement throughout the learning process (Vermeulen & Volman, 2024; Vo & Ho, 2024). The effectiveness of the e-module is reflected in improved student learning outcomes following its implementation. The average pretest score of 31.67 increased to 92.92 on the posttest, with an N-gain of 0.90, which is considered high. This improvement indicates that integrating PBL syntax into the e-module encourages students to identify problems, explore information, discuss, and develop solutions independently. These activities make students more active in building conceptual understanding than learning oriented towards the teacher's delivery of information.

The findings of this study confirm that the application of PBL combined with interactive multimedia can create more meaningful learning. Using contextual problems as a starting point for learning provides students with opportunities to connect mathematical concepts to real-world situations, while interactive multimedia helps them visualize abstract concepts. The combination of the two creates a learning environment that not only improves learning outcomes but also encourages student engagement and independence throughout the learning process. Overall, this research contributes to the development of innovative digital teaching materials in mathematics learning. The research's novelty lies not only in the development of digital-based e-modules, but also in the integration of Problem-Based Learning syntax into each learning activity, supported by interactive multimedia. This approach produces teaching materials that meet the aspects of validity,

practicality, and effectiveness while supporting the implementation of student-centered learning in accordance with the demands of the Independent Curriculum.

CONCLUSION

This research successfully developed an interactive e-module integrated with *Problem-Based Learning* (PBL) on matrix material for Grade XI Phase F of Senior High School that meets the criteria of validity, practicality, and effectiveness as a digital teaching material. The development of the e-module, based on needs analysis, student characteristics, and the demands of the Independent Curriculum, resulted in a product that integrates material presentation, interactive multimedia, and problem-solving-based learning activities into a systematic learning unit. The implementation of the e-module has been shown to positively impact student learning outcomes, as indicated by increased *posttest scores* and *N-gain scores* in the high category. These findings confirm that integrating Problem-Based *Learning* with interactive e-modules not only improves the quality of teaching materials but also fosters a more active, contextual, and student-centered learning experience. Thus, the developed e-module has the potential to be an alternative innovation in mathematics learning that supports the implementation of the Independent Curriculum and strengthens students' conceptual understanding and mathematical problem-solving abilities.

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