

IMPACT OF RME-BASED E-MODULES ON ENHANCING STUDENTS' UNDERSTANDING OF FUNCTIONS AND CRITICAL THINKING

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Abstract

This study is based on the fact that mathematics learning materials have been unappealing, causing students to quickly become bored and saturated with the learning situation. This has resulted in students not actively participating in lectures, revealing a low level of student conceptual understanding and critical thinking in the context of functions. The research focuses on developing an interactive e-module specifically for university students on the topics of properties and operations of functions, function composition, inverse functions, and function limits, particularly for those in the Information Systems program at ITB STIKOM Bali. The e-module, which integrated RME principles such as contextual problems and self-directed learning, was tested using a development research design based on the Plomp model with three methodological phases: preliminary research, development or prototyping phase, and assessment phase. The research data collection methods used were from questionnaires for lecturer and students, observation results of lecturer and students during the trial, interviews with lecturers and students, also essay tests for students. The results of the Paired Sample T-Test, it is known that the p -value = $0.000 < 0.05$, indicating a significant difference between the pre-test and post-test scores in students' conceptual understanding and critical thinking abilities. Additionally, an RME-based e-module was developed with the following characteristics: (1) provides instructions that facilitate self-directed learning for contextual problems, supported by GeoGebra technology; (2) Incorporates RME characteristics (both "model of" and "model for") to enhance critical thinking and conceptual understanding; (3) Not dependent on other teaching materials because its content is interconnected and self-sufficient; (4) interactive and adapts to technological advancements, making it accessible on both Android and iOS devices; and (5) Allows for independent evaluation through quiz questions and formative test questions using Google Forms features. The study offers a model for future applications of RME in higher education.

Keywords: Conceptual Understanding; Critical Thinking; E-Module; Realistic Mathematics Education

Abstrak

Penelitian ini didasari pada bahan belajar matematika selama ini tidak menarik, sehingga membuat mahasiswa cepat jenuh dan bosan dalam situasi belajarnya. Hal tersebut mengakibatkan mahasiswa tidak berperan aktif dalam perkuliahan, yang mengungkap rendahnya tingkat pemahaman konseptual dan berpikir kritis mahasiswa dalam konteks fungsi. Penelitian ini berfokus pada pengembangan e-modul interaktif yang dirancang khusus untuk mahasiswa pada topik sifat dan operasi fungsi, komposisi fungsi, invers fungsi dan limit fungsi, khususnya pada program studi Sistem Informasi di ITB Stikom Bali. E-modul yang mengintegrasikan prinsip-prinsip RME, seperti masalah kontekstual dan pembelajaran mandiri, diuji dengan desain penelitian pengembangan berdasarkan model Plomp dengan 3 tahapan metode, yaitu preliminary research, development/fase prototyping, dan assessment. Metode pengambilan data penelitian yang digunakan berasal dari hasil kuesioner untuk dosen dan mahasiswa, hasil observasi terhadap dosen dan mahasiswa selama uji coba, wawancara kepada dosen dan mahasiswa, serta tes esay yang ditujukan untuk mahasiswa. Hasil uji Paired Sample T-Test, diketahui nilai $p = 0.000 < 0.05$, sehingga ada perbedaan yang signifikan antara skor pre-test dan post-test dalam pemahaman konsep dan kemampuan berpikir kritis mahasiswa. Selain itu, telah dihasilkan e-modul berbasis RME dengan karakteristik: (1) terdapat instruksi yang membantu belajar secara mandiri terhadap masalah kontekstual difasilitasi teknologi GeoGebra; (2) memiliki

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karakteristik RME (model of dan model for) untuk kemampuan berpikir kritis dan pemahaman konsep; (3) tidak tergantung pada bahan ajar lain karena memiliki sajian materi saling terkoneksi; (4) interaktif dengan mengadaptasi perkembangan IPTEK yang dapat diakses dari android dan iOS; dan (5) dapat melakukan evaluasi secara mandiri pada soal kuis dan soal tes formatif menggunakan fitur Googleform. Penelitian ini menawarkan model untuk aplikasi RME di pendidikan tinggi di masa depan.

Kata kunci: Berpikir Kritis; E-Modul; Pemahaman Konsep; Realistic Mathematics Education



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INTRODUCTION

The evolving landscape of education requires innovative approaches to address the diverse learning needs of students. In the context of mathematics education, one significant challenge is enhancing students' conceptual understanding and critical thinking skills, particularly in subjects like functions (Arisoy & Aybek, 2021; Jamil et al., 2024).

Based on interviews with lecturers, it's a fact that current learning strategies and methods don't sufficiently help students develop by supporting them in active learning to grasp concepts and think critically. The updated standards for mathematics learning processes can't be realized if the learning process doesn't emphasize conceptual understanding and critical thinking. Wulandari & Darminto (2016) conducted a study on the examined the impact of critical thinking abilities and concept comprehension on mathematical problem-solving abilities and found a correlation between the three.

A study conducted by Cahyono (2017) states that every mathematics lesson conducted should always pay attention to students' critical thinking skills. To see the profile of students' critical thinking, researchers can look at the students' activities in solving problems using their conceptual understanding. From this, the researcher concluded that students with a high level of critical thinking also have a

good conceptual understanding. Conversely, students with a low level of critical thinking achieve a low level of conceptual understanding. Critical thinking skills must be developed in students first, so that the learning process toward conceptual understanding can be seen clearly.

Based on interviews with several students from the ITB Stikom Bali Information Systems program, students feel that mathematics is an unlikable subject. They believe that the learning materials are uninteresting, which makes them quickly feel saturated and bored during class. This leads to students not being actively involved in lectures. However, an active and engaging learning process plays a crucial role in students' critical thinking skills (Maharani et al., 2024). Students also stated that the provided teaching materials are impractical and lack relevance to their lives.

Jumrah & Anggriani (2022) argued that most students are not guided to apply mathematics to real-life situations. This is what makes mathematics learning less meaningful. Students are not given enough opportunities to rediscover and construct mathematical ideas on their own. According to Pratiwi & Indarini (2021), connecting real-life experiences with mathematical ideas in learning is important for meaningful learning to occur.

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Based on interviews and observations of teaching materials used by lecturers in the Information Systems program at ITB STIKOM Bali, the weaknesses of using modules in the learning process for functions have been: (1) student difficulties were not immediately addressed; (2) the teaching materials were unengaging, which led to student boredom during learning; (3) modules were not interactive and offered few practice problems, impacting the improvement of conceptual understanding and critical thinking skill; (4) modules lacked contextual problems, resulting in a lack of student motivation to learn; (5) printing modules incurred costs; and (6) the printed format of modules was impractical, making it difficult to learn anywhere and anytime. E-module is considered more suitable for students in the Information Systems program at ITB STIKOM Bali because their learning preferences in lectures align more closely with and are drawn to digital learning resources.

In an effort to optimize learning to make it more appealing to students in studying functions, a medium is needed for mathematics learning, especially for the topic of functions, to maximize the lecture process both online and offline. The researchers have also conducted studies on the factors influencing students' interest in using e-module as learning resources, which showed that students have a high interest in utilizing learning media such as e-modules. One of the effective strategies to improve students' ability to solve mathematical problems is through the use of electronic learning modules (Hendriko et al., 2024).

Similar studies have been conducted, including the following by Aspriyanti & Suzana (2020) This study

on an RME-based e-module found that There is an improvement in student learning achievement between before and after being given the learning e-module, and it can have a positive effect on improving student learning outcomes. The same research is also explained by Hilaliyah (2019) This research concluded that the average validation of the teaching material by experts was 85%, which is considered "good." The e-module's practicality was rated as "very practical," with an average of 82% from educators and 90% from students. Students' responses to the e-module's appearance averaged 89%, falling into the "good" category. Students' mathematical literacy skills reached 93%, which is considered effective. Mathematical literacy, as defined in the PISA 2015 assessment framework, is an individual's basic ability to interpret, formulate, and apply mathematics in various contexts. This includes the ability to reason logically and use mathematical algorithms, concepts, facts, and tools to describe, estimate, or explain a phenomenon or event. Other research described by Wulandari & Darminto (2016) The results of this study showed that the e-module's validity percentage was 91.74%, categorized as "very valid". The practicality score was 82.26%, which is considered "very practical." The effectiveness score was 75.61%, categorized as "effective."

Based on the findings from these researchers, it can be concluded that the development of an RME-based e-module is believed to be capable of improving conceptual understanding and critical thinking, provided the e-module is valid, practical, and effective for use.

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However, it has been seen that the development of RME-based e-modules on function material has only been carried out at the school level. In fact, one of the mathematics learning approaches that encourages college students to be able to relate mathematics to the real world is the RME approach. Several studies verify that RME can be applied effectively, can facilitate mathematical understanding and abilities, and can help students in understanding the practical applications of mathematics (A. P. Lestari et al., 2025; Sapi'i, 2020). So in this case, the development of RME-based e-modules at the college level on function material is a necessity along with the characteristics possessed in e-modules as novelty, namely the characteristics of RME-based e-modules on function material: (1) Instructions support independent learning on contextual problems (2) have RME characteristics (model of and model for) for conceptual understanding and critical thinking skills (3) do not rely on other teaching materials due to their interconnected material presentations (4) are interactive by incorporating science and technology advancements that are accessible from iOS and Android and (5) are capable of conducting independent assessments on quiz questions and formative test questions.

The importance of developing this e-module as a solution lies in its potential to boost student motivation for learning about functions, whether independently or in groups, with or without an educator guidance. By introducing an interactive e-module that integrates RME principles, this study aims to empower students with the necessary tools to engage more deeply with mathematical content. Furthermore, the development of this e-module

could serve as a model for other institutions seeking to enhance their teaching methods in the digital era with an RME basis, where online learning and interactive media are increasingly central, reinforcing that mathematics is not just a calculation-based science but rather a discipline closely connected to students' lives.

This research will contribute to the literature by exploring how an RME-based e-module can improve conceptual understanding and critical thinking specifically in the context of functions at the university level, thus filling a crucial gap in the current educational landscape.

METHODS

This study used a development research design following the Plomp model to create an e-module based on realistic mathematics education (RME) for teaching functions to students in the Information Systems program at ITB Stikom Bali. The research process was structured into three phases: preliminary research, development and prototyping, and assessment. This approach allowed for an iterative development of the e-module, followed by rigorous testing and evaluation.

Research Design

The research design adhered to the three-phase Plomp model (Plomp, 2013), which includes the following stages:

1. Preliminary Research:

The preliminary phase focused on identifying the challenges and needs of both students and instructors concerning the teaching of mathematical functions. This was achieved through classroom observations and interviews with faculty members. Insights gathered from these interactions revealed the need for a more engaging and contextually

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relevant approach to teaching functions. Specifically, students struggled to connect mathematical concepts to real-world applications, and the teaching materials were not conducive to fostering critical thinking skills. Based on these findings, the need for an e-module based on RME was identified as a solution to address these challenges. Additionally, an initial draft of the characteristics for the RME-based e-module for learning functions was compiled. This initial draft was referred to as draft I.

2. Development and Prototyping:

During this phase, an initial draft of the e-module was developed, incorporating RME principles such as the use of contextual problems, interactive learning activities, and self-directed problem-solving. The e-module was designed to guide students through functions by engaging them in real-world scenarios and promoting critical thinking.

The first version of the e-module was reviewed by three experts two in mathematics education and one in media development to validate its content, instructional design, and usability. Expert feedback focused on ensuring the e-module's alignment with RME principles and its suitability for enhancing students' understanding of functions. Revisions were made based on the validation test results, leading to a valid and high-quality draft of the e-module for learning functions, which was called draft II.

Based on this feedback, the e-module was revised and tested to a limited trial with a small group of 10 students, consisting of 5 males and 5 female. This heterogeneity was maintained to ensure the trial class remained representative. The main goal of this limited trial was to gain insights

into the e-module's characteristics and assess its feasibility. The evaluation results from this phase were used to identify shortcomings and generate suggestions for improvement, leading to what was termed draft III.

After draft III was developed, the research proceeded to field trial I. The focus of this trial was to enhance the quality of the mathematics e-module, making it a more practical and effective product. field trial I was conducted over 9 sessions with 40 students from the Information Systems program to gather more comprehensive data. The revision made based on the results of this trial led to draft IV.

3. Assessment:

The assessment phase in this research is closely linked to the previously conducted phases. In this stage, field trial II was carried out, involving a different class than those used in the limited trial and field trial I. The focus of this field trial II was to obtain the final product of the developed learning e-module, ensuring it was valid, practical, and effective. Field trial II was also conducted over 9 sessions with 40 students from the Information Systems program to gather more comprehensive data. However, due to time and cost constraints, the researchers only proceeded up to field trial II, with the content limited to the topic of functions. The assessment results were used as a basis for revision, leading to a valid, practical, and effective e-module prototype (the final product).

Data Collection Techniques

Data were collected using a combination of quantitative and qualitative methods to evaluate the effectiveness and practicality of the e-module. The instruments used in this study include

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13 aspects: e-module content validation sheets, e-module construct validation sheets, media validation sheets, e-module practicality response questionnaires from the lecturer's perspective, e-module practicality response questionnaires from the students' perspective, e-module effectiveness supporting questionnaires, e-module practicality observation sheets, e-module effectiveness supporting observation sheets, interview guides for e-module practicality from the students' perspective, interview guides for e-module practicality from the lecturer's perspective, interview guides for e-module effectiveness support, critical thinking skills test sheets, and conceptual understanding test sheets. All these forms were validated by two validators before the limited trial phase. After the learning e-module was content-validated, the next step was to see whether the learning e-module was construct-valid or not, for which the opinion of two experts was requested. Here's an explanation of each research instruments:

1. Pre-test and Post-test:

Pre-test and post-test are used when evaluating the effectiveness of the learning e-module, critical thinking skills tests and conceptual understanding tests were used. The students' conceptual understanding and critical thinking skills were assessed by administering a semi-summative test after Draft IV was trialed in Field Test I and Field Test II to see the product's effectiveness improvement. The test consisted of four essay questions for conceptual understanding and two essay questions for critical thinking. The indicator used as a benchmark for success in improving conceptual understanding and critical thinking skills is a minimum of a HIGH criterion.

2. Surveys and Questionnaires:

After three subject matter experts conducted content and construct of the instrument with a "valid" criterion, the next step was to evaluate the e-module's practicality and usability. Students and instructors completed surveys and questionnaires for this purpose. These instruments measured students' perceptions of the e-module's usability, interactivity, and effectiveness in supporting their learning. The instructors' questionnaires focused on their experiences using the e-module in the classroom and their observations of student engagement and performance, such as: the suitability of the material with the curriculum, the presentation of easily understandable material, the language used, and the usefulness of the material in their daily lives.

3. Observations:

Classroom observations were conducted throughout the implementation of the e-module. Observers focused on students' engagement with the e-module, their participation in group discussions, and their ability to independently solve problems using the e-module. Observers also noted the level of interaction between students and the content, as well as any challenges they encountered while using the e-module.

4. Interviews:

In-depth interviews were conducted with both students and instructors after the field trial. The interviews aimed to gather qualitative feedback on the strengths and weaknesses of the e-module, as well as suggestions for improvement. Students were asked about their experience using the e-module, its impact on their understanding of functions, and how it helped them develop critical thinking skills. Instructors provided insights into

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how the e-module fit into their teaching and any changes they observed in students' engagement and learning outcomes.

Data Analysis

The data collected from the pre-test and post-test were analyzed using both quantitative and qualitative methods:

1. Quantitative Analysis:

Descriptive statistics, including mean scores and standard deviations, were used to summarize the pre-test and post-test results. Paired sample t-tests with SPSS were conducted to assess whether the differences in students' scores before and after using the e-module were statistically significant, indicating improvement in conceptual understanding and critical thinking.

2. Survey and Questionnaire Analysis:

Responses to the surveys and questionnaires were analyzed using descriptive statistics to evaluate the practicality and effectiveness of the e-module. Responses were categorized based on themes such as usability, interactivity, and overall satisfaction. The data provided a comprehensive understanding of the e-module's impact from both the student and instructor perspectives. The scoring used in this data collection technique is the Likert Scale. The Likert scale is a five-point scale containing answer levels about a respondent's agreement with a statement or question presented before the provided answer options.

3. Qualitative Data Analysis:

The qualitative data from interviews and classroom observations were transcribed and analyzed using thematic analysis. Initial coding was applied to identify key themes related to

student engagement, critical thinking, and the overall effectiveness of the e-module. The themes were then categorized and analyzed to provide deeper insights into how the e-module supported student learning and fostered a more interactive, critical-thinking-driven approach to studying functions.

RESULTS AND DISCUSSION

Findings

The goal of this study was to create an e-module based on Realistic Mathematics Education (RME) to help students at ITB Stikom Bali improve their conceptual knowledge and critical thinking abilities in the function course. The following is a summary of the study's findings:

1. Preliminary Phase:

This phase involved an initial investigation to gather data on the needs of the field and improve the quality of classroom mathematics learning. The researcher's analysis of the current function module revealed that it was not engaging for students because it lacked context. This lack of context would certainly negatively affect the meaningfulness of their learning, as illustrated in the Figure 1.

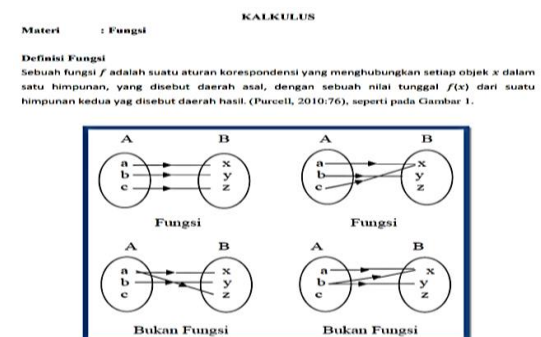


Figure 1. Conventional Module 1

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In addition, the practice problems in the module don't show students how the Calculus subject, specifically functions, can be applied in situations that are relevant to their own environment.

LATIHAN

1. Jika $f(x) = x^3 - 3$ tentukanlah nilai dari:
 - a. $f(2) = \dots$
 - b. $f(3) = \dots$
 - c. $f(-2) = \dots$
 - d. $f(-3) = \dots$
2. Diketahui bahwa $f(x) = x^2 + 1$ dan $g(x) = x + 1$, tentukanlah nilai dari:
 - a. $(g \circ f)(x)$
 - b. $(f \circ g)(x)$

Figure 2. Conventional Module 2

A summary of the lecturer interview revealed the need to develop an e-module to improve students' conceptual understanding and critical thinking. Currently, students struggle with these skills on the topic of functions, especially when solving real-world word problems. This lack of understanding prevents them from building their mathematical concepts. The new e-module should also be interactive and relevant to today's students. Traditional teaching often just shows students how to answer problems that are similar to examples, so when they encounter a more contextual problem, they don't know how to solve it.

2. Prototyping Phase:

This phase involves an iterative process of analysis, design and development, and formative evaluation and revision. These three steps are integrated into a single process for designing, developing, validating, and testing the product, followed by revisions. The analysis stage continues throughout as the foundation for revising the product.

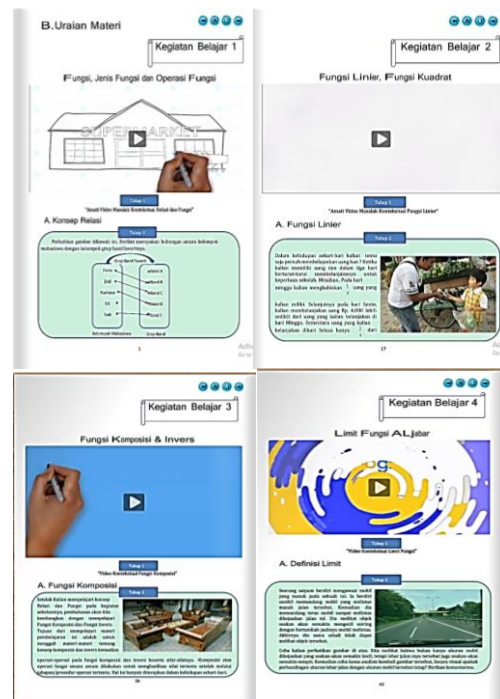


Figure 3. E-Module Design (Draft 1)

Based on Figure 3, the learning activities are split into four sections:

- a. **Activity 1:** discusses functions, types of functions, and function operations.
- b. **Activity 2:** covers linear and quadratic functions.
- c. **Activity 3:** focuses on composite and inverse functions.
- d. **Activity 4:** discusses the limits of algebraic functions.

Most of the function material is included completely and consecutively in each activity. When material is arranged systematically and with variety, it makes it easier for students to understand the content and motivates them to learn (Alim et al., 2021; Li et al., 2021).

The details of the e-module validation results and their supporting instruments are in Table 1.

Table 1. Summary of e-module and research instruments validation

Research Instrument	Validation Result	
	Validator I	Validator II
Validation Sheet for E-Module Content	Viable	Viable
Validation Form for the E-Module's Construct Sheet for Media Validation	Viable	Viable
E-Module Practicality Response Questionnaire	Viable with revision	Viable
Validation Sheet (From the Lecturer's Perspective)	Viable with revision	Viable
Validation Sheet for the E-Module Practicality Response Questionnaire (From Students)	Viable	Viable
E-Module Effectiveness Supporting Questionnaire Validation Sheet	Viable with revision	Viable
E-Module Effectiveness Supporting Observation Validation Sheet	Viable	Viable
E-Module Practicality Interview Guide (For Lecturers)	Viable with revision	Viable
E-Module Practicality Interview Guide (For Students)	Viable with revision	Viable
E-Module Effectiveness Supporting Interview Guide	Viable	Viable
Critical Thinking Skills Test Questions Sheet	Viable	Viable with revision
Conceptual Understanding Test Questions Sheet	Viable	Viable

The revised results from this validation test are then referred to as draft II. The next stage is to carry out a formative evaluation which consists of two parts: a limited trial and a field trial I. These trials aim to improve the developed learning e-module.

The limited trial activity was conducted over 5 meetings involving 10 students from class JA225, consisting of 5 male students and 5 female students, who represented the situation and conditions of the trial class. The selection of these students was based on a distribution of abilities and gender. This was done to ensure that the class used in the limited trial remained heterogeneous.

The focus of this trial activity was to get an overview of the characteristics and feasibility of mathematics learning using the e-module that had been prepared. In this trial, several assessment techniques were carried out,

such as observation, questionnaires, and interviews. The results were then used to revise draft II, and the revised version was called draft III.

The activities carried out in field trial I were, in principle, the same as those in the limited trial, but this trial was conducted with a larger number of students. Additionally, in field trial I, learning activities were carried out over 9 meetings.

Field trial I was conducted in class JA224 with 40 students. Class JA225 was not involved again because the focus of this trial was to improve the quality of the prepared learning e-module, making it a more practical and effective product.

In this trial, several assessment techniques were used, such as observation, questionnaires, interviews, and tests. The results were then used to revise draft III, and the revised version was called draft IV.

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3. Assessment:

During field trial II and at the end of the trial, a semi-summative assessment is carried out involving lecturers and students. In field trial II, no revisions or suggestions are made after the results of the field trial II are analyzed. Therefore, after field trial II, this draft IV becomes the final product.

a. E-Module Characteristics

The e-module developed in this study was validated as a high-quality educational tool, meeting the criteria of being valid, practical, and effective. The e-module integrated RME principles by

presenting mathematical concepts through real-world contextual problems, interactive features (such as quizzes, animations, and GeoGebra integration), and self-directed learning opportunities. The module was accessible via both Android and iOS devices, making it flexible for students' use in various contexts.

b. Improved Conceptual Understanding

The pre-test and post-test results showed a significant improvement in students' understanding of mathematical functions (Table 2.)

Table 2. Quantitative Analysis Results of Students' Conceptual Understanding

	N	Corelation	Sig
Pair 1 Pre_test & Post_test	40	,874	000

Source : by author

The correlation between Pre-Test and Post-Test is 0.874, which indicates a strong positive relationship. The significance value (Sig.) of $0.000 < 0.05$ indicates that this relationship is statistically significant. This indicates a strong positive relationship. It means that as students' scores on the Pre-Test increased, their scores on the Post-Test also consistently increased. It suggests that students who started with higher initial knowledge tended to perform better after the intervention, and vice versa. The Paired Sample T-Test results are considered significant if the the p value (Sig.) is less than the significance level (α) of 0.05. It is known that the value of $p = 0.000 < 0.05$, so there is a significant difference between the scores before and after treatment.

c. Enhancement of Critical Thinking

Students also showed notable improvements in critical thinking, as evidenced by the post-test scores measuring their ability to apply mathematical concepts to solve real-world problems.

Table 3. Quantitative Analysis Results of Students' Critical Thinking Skills

	Post_Test – Pre_Test
Z	-5,381 ^o
Asymp. Sig. (2-tailed)	,000

Source : by author

The output of the wilcoxon test can be seen in table. 3, namely the Asymp.Sig. (2-tailed) value of 0.000, where this value is smaller than the 5% alpha significance level (0.05). So, it can be interpreted that there are

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differences in the test results of students' critical thinking skills in learning mathematics. The e-module's use of contextual problems and its emphasis on critical thinking exercises such as mathematical modeling and problem-solving contributed to this improvement. These results confirm the potential of RME-based e-modules in fostering critical thinking, as previous studies have found that such approaches stimulate deeper cognitive processing and enhance students' ability to engage in higher-order thinking.

d. Practicality and Student Engagement:

The surveys and questionnaires completed by both students and instructors indicated high levels of satisfaction with the e-module. The module was deemed practical and easy to navigate, and students appreciated the flexibility to learn at their own pace. The integration of technology, particularly GeoGebra for dynamic visualizations, was seen as a significant factor in increasing student engagement.

These findings not only underscore the effectiveness of the RME-based e-module in improving students' understanding of functions but also raise important questions about the broader implications for mathematics education at the university level.

Discussion

The findings from this study provide valuable insights into the potential of e-modules based on Realistic Mathematics Education (RME) for enhancing the learning experience in university-level mathematics education, specifically in the context of teaching functions. These results contribute to the ongoing shift toward digital learning tools in higher

education, reflecting a broader trend in educational technology that emphasizes interactive, student-centered learning. Over the past decade, digital tools like e-modules, gamified learning platforms, and virtual simulations have transformed traditional teaching methods, offering more personalized and engaging learning experiences. By integrating these technologies into mathematics education, this study demonstrates how RME-based e-modules can address persistent challenges in understanding complex concepts, improving students' conceptual comprehension, and fostering critical thinking.

Discussion on the Validity of the Learning E-Module

The development of an RME-based e-module has not been carried out by the lecturers; more specifically, the teaching lecturers have not utilized the current advancements in information technology. One way is to create an e-module with Flip PDF Professional. The features in this application can combine files such as PDFs, images, animations, videos, audio-visuals, YouTube links, and hyperlinks (Lestari et al., 2022).

Research conducted by Mampouw et al. (2023) states that an e-module based on the Flip PDF Professional application is effective for increasing students' independence and cognitive learning outcomes. In addition, research conducted by Lestari, et al. (2022) says that an e-module based on Flip PDF Professional can help foster students' understanding. An e-module based on Flip PDF Professional is also flexible, meaning it can be used anywhere, either online or offline, and is not time-dependent."

The learning e-module developed in this study can be said to meet the content validity aspect because the

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development process was in accordance with the Plomp development procedure and the RPS (Semester Learning Plan) applied on campus.

Meanwhile, construct validity was assessed from the consistent relationship between each component of the developed learning e-module and the characteristics of the applied learning. To see the construct validity of the learning e-module, experts (validators) were asked for their opinion using a research instrument that had been previously tested for its validity. The results of the expert consideration obtained an S_r score of 3.625, which indicates that the developed e-module has a very valid criterion.

From the media validity aspect, a media expert also assessed whether the components of the e-module could be used as they should be. The result of the media expert's consideration obtained an S_r score of 3.27, which indicates that the e-module media has a valid criterion.

The RME-based e-module received a very good and feasible qualification to be used as a learning resource. This feasibility is influenced by the fact that the e-module's development process used a systematic development model, namely Plomp, which starts from the analysis, design, and development stages, to product trials and improvements, thereby supporting the success of the e-module's development.

Discussion on the Practicality of the Learning E-Module

The practicality measurement of the learning e-module in this study aimed to determine whether the developed e-module was easy or difficult to use. To determine the practicality of the e-module, observa-

tions were made on the practicality of learning using the developed e-module during each learning activity.

In addition, data from student and lecturer response questionnaires were collected at the end of the trial to identify weaknesses and serve as a basis for evaluating and revising the learning e-module. This was followed by interviews with a number of students.

To address any difficulties lecturers might have in implementing learning with the developed e-module, the researcher first conducted several socialization meetings with lecturers at ITB Stikom Bali before the classroom trials. This involved explaining the characteristics of the RME-based mathematics learning e-module and the steps to be taken in the learning process. Therefore, the lecturers who would be applying this e-module already had an understanding and prior knowledge of the learning e-module to be implemented.

Based on the results from the practicality observation sheet of the learning e-module during the limited trial, it was categorized as very practical with an average score of 3.544. This is because the S_r value fell within the acceptable range. During the limited trial, which lasted up to 4 learning sessions, the observations showed that lecturers did not experience difficulties. This was because the researcher had socialized with the class lecturers beforehand, who would assist in conducting the research on the RME-based mathematics learning steps and the agreed-upon RPS (Semester Learning Plan), which would help the lecturers in their teaching.

In the limited trial, the lecturer covered the topic of functions. During this trial, there were some obstacles for both lecturers and students during the

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activities, which were observed. Some students were still not participating well in discussions because they were hesitant to answer the questions posed by the lecturer. When answering problem questions or given exercises, students used a brief method that focused only on whether their answer was correct, while the process they used was still not clear enough.

To overcome these obstacles, several steps were taken as a solution: guiding and supervising students during discussions, approaching students who were not focused on learning, and the lecturer providing probing questions such as "Why is it like that?" or "Where did you get that solution from?". By providing probing questions, students would try to communicate with their group members or the lecturer and concentrate more during the discussion. Through these steps, students became more focused, and no one was out of the loop. With these steps and approaches, it was hoped that the problems and obstacles faced in the limited trial would not reappear in field trial I and field trial II.

Based on the lecturer response questionnaire from the limited trial, an average score of 3.235 was obtained, which indicates that, according to the lecturers, the designed e-module is practical to use. Meanwhile, the student response questionnaire from field trial I obtained an average score of 3.544, indicating that, according to the students, the e-module is very practical to use.

In the subsequent trial, field trial I, there was an increase in the average score of the learning e-module practicality observation. The average score obtained was 3.57, where the e-module was still categorized as very practical. Lecturers felt comfortable in

carrying out the learning process because they did not have to carry many books. Meanwhile, students began to feel the benefits of using the learning e-module.

Based on the lecturer response questionnaire, an average score of 3.588 was obtained. This shows that, according to the lecturers, the designed e-module is very practical to use. Meanwhile, based on the student response questionnaire, an average score of 3.64 was obtained. This shows that, according to the students, the e-module is practical to use.

The next step was field trial II. In field trial II, there was an increase in the average score of the learning e-module practicality observation in learning. The average score obtained was 3.72, which falls into the very practical category. Based on the lecturer response questionnaire, an average score of 3.88 was obtained. This indicates that, according to the lecturers, the designed e-module is very practical to use. Meanwhile, based on the student response questionnaire, an average score of 3.86 was obtained. This indicates that, according to the students, the e-module is practical to use.

Based on the description above, it can be said that the developed learning e-module has met the aspect of practicality. This can be seen from the analysis of student responses, lecturer responses, and the practicality observation sheet during the limited trial, field trial I, and field trial II.

According to Aulia & Prahmana (2022), a developed teaching material is declared practical if it is easy to use. "Easy to use" means it is easy for students to learn, so that independent learning becomes easy to implement, interesting, enjoyable, and can increase creativity. Good and practical teaching

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material is one whose material has been formulated appropriately so that it is easy to understand (Inganah et al., 2023).

Discussion on the Effectiveness of the Learning E-Module

The e-module was designed to promote self-directed learning, where students take ownership of their learning process (Sanova et al., 2022). The interactive elements such as quizzes, problem-solving tasks, and simulations provided students with opportunities to explore mathematical concepts at their own pace, reinforcing critical thinking skills. Instead of passively receiving information, students actively applied mathematical concepts to solve real-world problems, requiring them to think critically about the content and their approach.

For instance, students used GeoGebra to experiment with different transformations of functions, testing hypotheses and analyzing results in real-time. This hands-on approach helped students develop a problem-solving mindset, as they were not only learning mathematical concepts but also applying them to unfamiliar situations, which fostered higher-order thinking (Ariati & Juandi, 2022; Darto, 2021; Sukmawati, 2018).

The effectiveness of the learning e-module was measured to see how well its implementation could improve students' conceptual understanding and critical thinking skills. At the end of the learning activities in field trial I and field trial II, students were given an essay test with 4 questions for conceptual understanding and 2 questions for critical thinking skills. This test was used to measure students' conceptual understanding and critical

thinking skills based on pre-determined indicators.

Based on the results of the student conceptual understanding test in field trial I, 20% of students had a conceptual understanding in the Moderate category, 75% were in the High category, and 5% were in the Very High category. There was an increase in the results of the student conceptual understanding test in field trial II, where 77% of students had a conceptual understanding in the High category, and 23% had a conceptual understanding in the Very High category.

In addition, based on the results of the student critical thinking skills test in field trial I, 7% of students had critical thinking skills in the Low category, 70% were in the Moderate category, and 23% were in the High category. There was also an increase in the results of the student critical thinking skills test in field trial II, where 10% of students had critical thinking skills in the Moderate category, 82% were in the High category, and 8% were in the Very High category.

There were also results from the student-filled supporting questionnaire for e-module effectiveness. In field trial I, the average score obtained for supporting e-module effectiveness was 37.75, which is categorized as very good. In field trial II, the average score increased to 37.9, still in the very good category. This is consistent with the observation results during student learning, where in field trial I, the average score for the effectiveness support observation was 27.062, categorized as very good. Similarly, the average score in field trial II increased to 29.075 with the same category of very good.

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This is supported by research conducted by Pitriani & Pratama (2021), which found that the use of RME-based teaching materials is better at improving students' mathematical understanding skills compared to conventional learning. In addition, according to research by Febriani & Sidik (2020), the RME approach has several advantages in helping to improve students' critical thinking skills, such as making it easier to understand mathematical concepts, fostering students' interest and motivation in learning, and facilitating interaction and cooperation among students. RME learning works by linking reality with the learner's experience and is very suitable for mathematics learning (Lady et al., 2018). The RME learning method involves every student in sharing perceptions, engaging in group discussions to exchange ideas, and obtaining new mathematical concepts through problem-solving (Ariati et al., 2022).

Based on the above explanation, the learning e-module has been proven to meet the criteria of being effective because it can improve students' conceptual understanding and critical thinking skills.

Below is a snippet of the student answers from student code R22, class JV225, on the critical thinking skills test questions.

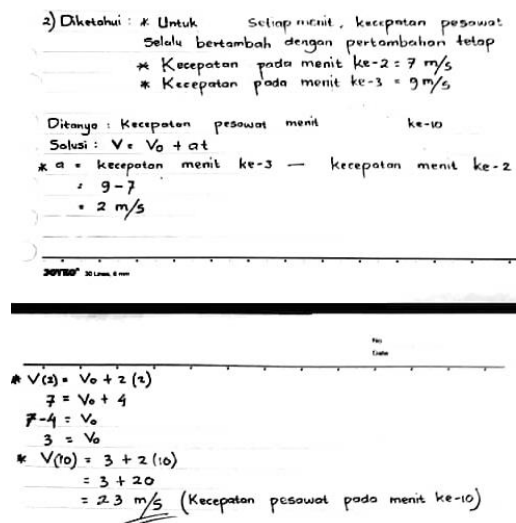


Figure 4. Critical thinking test answer results from student code R22

Based on the researcher's review of the student's answer, it is evident that the student's solution has a different flow or idea compared to the previously created answer rubric. The solution method used by student code R22 is more effective, even though some steps of the work do not align with the grading rubric.

Overall, student code R22 was able to convert the word problem into a mathematical model and use their logical thinking to find the value of "a". According to the interview, student code R22 used the concept of linear functions from the developed RME-based e-module. However, student code R22 was also unable to write a conclusion and articulate the conjectures and coherence of the answers with the subsequent answers. Therefore, it can be concluded that a well-embedded concept will also result in good critical thinking to solve mathematical problems.

However, something different happened with student code R20 from class JA224 when asked the same question after completing the semi-summative test.

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The following is a snippet of the critical thinking test answer from student code R20 from class JA224.

$$\begin{aligned}
 & 1. w : 50.000 + 170.000 \\
 & \quad (t+2)^2 \\
 \text{Lm. w} & : (50.000 + 170.000) \\
 & \quad t+2^2 \\
 & : 0 - 40.000 \\
 & \quad (t+1)^2 \\
 & - 490.000 \\
 & \quad (t+2)^2 \\
 \text{Lm} & - 40.000 - 1 \\
 & \quad (t+1)^2 \\
 \text{Lm} & - 40.000 \\
 & \quad t^2 \times (1+2x^2) \\
 \text{Lm} & - 40.000 \cdot \frac{1+1}{2t^2} \\
 & = 0 \quad \text{is} \quad = 0 \quad (\text{kemungkinan kesalahpahaman yang dialami siswa dengan 50.000 orang})
 \end{aligned}$$

Figure 5. Critical thinking test answer results from student code R20

Based on the work done by student code R20, it is evident that the student was less capable of answering the question well and had an incorrect final result. This is one of the difficulties that the researcher and observer 2 noticed and observed with student code R20. This is also consistent with the results of student code R20's conceptual understanding test answers.

$$\begin{aligned}
 & b). (2x^2 + 5x + 3) - (x^2 + 4x - 3) \\
 & = 2x^2 + 5x + 3 - x^2 - 4x + 3 \\
 & = x^2 + x + 6 \\
 & 4. 1. Luas kolam : (10-x)^2 + (8-x)^2 + 20 \\
 & = (100 - 20x + x^2) + (64 - 16x + x^2) + 20 \\
 & = 36 - 4x^2 + 20x + 20 \\
 & = -4x^2 + 20x + 64 \text{ m}^2
 \end{aligned}$$

Figure 6. Conceptual understanding test answer results from student code R20

On question number 4 of the conceptual understanding test, the student was unable to use and combine previously learned concepts to solve the problem. This might be because the student did not try to follow the learning flow well during the learning activity.

After further discussion with the teaching lecturer, the researcher obtained information that the student tends to have an introverted personality during lectures. As a result, the lecturer has always guided this student because student code R20 was unwilling and shy to ask their friends. In fact, when learning in class with a regular module, the lecturer rarely had a Q&A session with this student. However, when the lecturer asked questions related to the function material in everyday life in the e-module, student code R20 appeared enthusiastic, although they still needed more in-depth guidance on how to express their ideas in writing.

Based on the discussion above, it can be concluded that the developed learning e-module has met the criteria of being **valid, practical, and effective**, which differentiates it from the learning tools currently in use.

Discussion on the Characteristics of the RME-Based E-Module

An e-module has a brief description of the material, its relevance to students' lives, expected learning outcomes, and instructions for using the RME-based e-module. After that, learning with the e-module begins by introducing students to real-life phenomena and problems through an animated video that contains audio, images, or concept maps.



Figure 7. Contextual problems video

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The phenomena studied can be obtained through observation. This is done so that students can directly see the benefits of the material being studied. A situation is a problem for a student if they realize there is an issue in that situation, know that the issue needs to be solved, feel motivated to act and solve it, but cannot solve it immediately.

Gravemeijer (2020) states that the learning process with a realistic approach uses contextual problems as a starting point for learning mathematics. Ibrahim et al. (2021) states that starting from a real-life contextual problem, students are guided to discover their mathematical knowledge by solving the problem.

The developed e-module is also able to guide students to solve problems through horizontal mathematization and vertical mathematization. This aligns with the directions provided in the e-module to help them express their concepts and critical ideas.

At this stage, they are invited to get used to doing horizontal and vertical mathematization.

Horizontal mathematization provides an understanding of how to guide students to explain using their critical thinking process. Students can use their conceptual understanding of relations to explain the solution to the given problem.

As shown in Figure 8, students are introduced to solving problems from an informal to a formal (mathematical language) approach. In the informal stage, horizontal mathematization occurs when they try to solve the problem by reasoning about the relationship between the students' names and their blood types. Horizontal mathematization in this case is seen when they try to describe and then group that relationship into a table (model of). Based on the facts observed in the informal analysis, they can easily continue with a formal solution (vertical mathematization) based on the theory learned previously.

Thus, horizontal mathematization only serves to help bridge students in obtaining a solution before answering using mathematical language. In Figure 8, students are helped to present the solution using an arrow diagram that contains mathematical symbols with specific meanings and purposes (model for).

Mathematical science, specifically the topic of functions, consists of various interrelated topics, such as relations. However, these connections are not only between topics within mathematics but also between mathematics and other disciplines, and between mathematics and everyday life. This interconnectedness is what is called mathematical connection.

b. Fungsi Surjektif

Suatu fungsi $f: A \rightarrow B$ disebut fungsi surjektif atau fungsi onto atau fungsi kepada jika dan hanya jika daerah hasil fungsi f sama dengan himpunan B atau $R_f = B$.

Contoh:

Pada suatu kelas, seorang dosen sedang memenuhi data golongan darah mahasiswanya. Diperoleh relasi berupa Ratna memiliki golongan darah A, Heri Memiliki Golongan darah B, Yadi memiliki golongan darah AB, Zaenal memiliki golongan darah O, dan Eko memiliki golongan darah B. Selidiki apakah relasi yang terbentuk merupakan fungsi surjektif?

Jawaban:

Berdasarkan uraian di atas dapat dijelaskan dalam bentuk model informal sebagai berikut:

Dalam situasi ini terdapat pengklasifikasian 2 kelompok, yaitu kelompok nama dan kelompok golongan darah.

Aturan hubungan yang terjadi : Golongan Darah
 $A : \{Ratna, Heri, Yadi, Zaenal, Eko\}$, $B : \{A, B, AB, O\}$

Nama	Golongan Darah
Ratna	A
Heri	B
Yadi	AB
Zaenal	O
Eko	B

Setelah uraian model informal di atas, dapat dilanjutkan berupa matematika formal sebagai berikut:

Fungsi $f: A \rightarrow B$ dinyatakan dalam pasangan terurut:
 $f = \{(Ratna, A), (Heri, B), (Yadi, AB), (Zaenal, O), (Eko, B)\}$.

Tampak bahwa daerah hasil fungsi f adalah $R_f = \{A, B, AB, O\}$ dan $R_f = B$ maka fungsi f adalah fungsi surjektif atau fungsi onto atau fungsi kepada. Fungsi $f: A \rightarrow B$ disebut fungsi into atau fungsi ke dalam jika dan hanya jika daerah hasil fungsi f merupakan himpunan bagian murni dari himpunan B atau $R_f \subset B$.

Figure 8. Horizontal and vertical mathematization in the e-module

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Tahap 3

Ayo Berlatih Bersama

- Cobalah temukan bentuk-bentuk "PEMBOROSAN" di dalam kehidupan di rumah kalian (misalkan: membiarkan keran air tetap menetes meskipun sudah dicoba ditutup rapat, menyalakan lampu di siang hari, menyalakan AC/ kipas angin sepanjang hari, dan lain-lain)
- Dan apa bahayanya jika dibiarkan pemborosan tersebut?
- Buatlah model sederhana untuk menentukan restiko pemborosan tersebut! Kemudian, dari kejadian tersebut apakah merupakan fungsi atau bukan? (berikan alasannya)

Memahami Masalah:
 Agar dapat memahami masalah maka lakukanlah investigasi di sekitar kalian yang menunjukkan "PEMBOROSAN" dengan Hp/android kalian. Lalu susunlah sebuah rumusan masalah sesuai soal!

.....

Menjelaskan Masalah:
 Buatlah model informal terkait relasi antara bentuk pemborosan dan dampaknya! Kemudian jelaskan syarat perlu dan cukup sebuah relasi dapat disebut sebagai fungsi!

.....

Menyelesaikan Masalah:
 Jelaskanlah jawabanmu yang sebelumnya ke dalam simbol matematika!
 Pilihlah prosedur yang tepat dan lakukan deduksi!

.....

Mendiskusikan Jawaban:
 Cermatilah dan bandingkan jawaban yang kamu peroleh dengan temanmu dan jelaskan perbedaan yang terjadi sesuai algoritma sifat-sifat fungsi!

.....

Memimpulkan:

.....

Figure 9. Connecting the Material

Based on the similar understanding of mathematical connections that have been previously stated, NCTM (2000) summarizes the indicators of mathematical connections into three major components: a) Recognizing and using the relationships between ideas in mathematics; b) Understanding the interconnectedness of mathematical ideas and forming new mathematical ideas to create a comprehensive connection; c) Recognizing and applying one mathematical content to another mathematical content and to environments outside of mathematics.

A mathematical concept has a connection with other concepts, so when learning a certain concept in mathematics, prerequisites from other concepts are needed. When students learn the topic of functions, they must first understand relations because that topic is related to functions.

In the classroom process, students are asked to discuss with their group members to compare answers and argue about the results obtained. According to Sukmawati (2018), interactive teaching means that students explain and give reasons for the answers they provide, understand their friends' (other students') answers, agree with their friends' answers, state their disagreement, look for other alternative solutions, and reflect on every step taken or on the learning outcomes.

The implementation of RME learning activities must have a special characteristic in its interactive method: after finding a solution, students are directed to discuss their solutions (which are often different, both in process and result). During the discussion, if students face difficulties in answering a question, the e-module also provides a "HELP" column that assists students in solving the contextual problem.

From the "HELP" menu, students will be directly connected to GeoGebra to further solidify their understanding without having to wait for the lecturer's explanation. Students can immediately explore their critical thinking and understanding using GeoGebra. The e-module makes it very easy for students to learn anywhere.

Tahap 4

Coba kamu diskusikan dengan temanmu, dari penjelasan konsep fungsi di atas, yang manakah merupakan domain dan range? Sertakan alasannya!

HELP

Figure 10. Appearance of the "HELP" Menu

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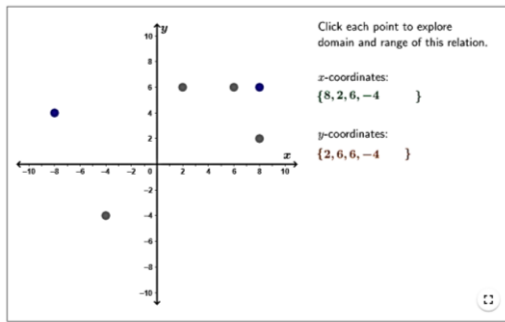


Figure 11. Appearance of the Content in the “HELP” Menu (GeoGebra)

The use of GeoGebra as an element of science and technology is an attraction for students because it can be accessed on both Android and iOS devices.

Figure 12. E-Module Supporting Technology Features for Self-Evaluation

The last technological application is the Formative Test. The formative test activity is interactive and uses Google Forms. Besides seeing their scores, students can also see which questions they got wrong so they can perform a self-evaluation.

Google Forms is an efficient tool for daily assessments. It is particularly efficient in preparing logistics for daily assessments, collecting answers, processing the results, and the procedures for conducting the daily

assessment (Marlinda, 2021). Self-assessment can also be done in Google Forms because students will immediately know their score and which points, they answered incorrectly. Although it consists of 20 objective questions, some of the questions provided are capable of honing students' critical thinking and conceptual understanding. An objective multiple-choice test has also been developed by Ningsih (2014) for the analysis aspect of critical thinking skills.

In addition to its advantages, the multiple-choice objective test format also has disadvantages, including the time it takes to create good questions, especially creating answer choices that are relatively similar in sentence length and the material used. The multiple-choice objective test format can also encourage students to be dishonest in answering. Students who do not understand the material may choose answers randomly or cheat from their friends, which affects the quality of the expected results.

Based on the shortcomings of multiple-choice questions, the researcher has a solution: to add essay practice questions in the assignment and discussion forum pages and to use a question randomization method for each student accessing the questions on Google Forms.

This condition allows the RME-based e-module to be categorized as a main module, as it does not require other teaching resources and all features are available to assist the learning process. The research by Husnulwati et al. (2019) states that an e-module is self-instructional if it includes the following: (a) clear learning objectives, (b) a systematic arrangement of the material, (c) learning material that displays illustrations and examples, (d)

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a summary and assignments to measure student learning outcomes, (e) assignments and questions that are appropriate to the material, context, and student environment, (f) the use of simple and communicative language.

In addition, the e-module also contains a list of references if students want to try other questions related to the function material.

CONCLUSIONS AND SUGGESTIONS

E-module based on Realistic Mathematics Education (RME) have been successfully developed for teaching functions to improve the conceptual understanding and critical thinking skills of Information Systems students at ITB STIKOM Bali. These e-module have met the criteria for validity, practicality, and effectiveness. The characteristics of the RME-based e-module on function material are as follows: 1) It provides instructions that assist students in learning independently through contextual based problems. 2) It possesses RME characteristics (“model of” and “model for”) that support the development of critical thinking and conceptual understanding. 3) It is self-contained, as the presented material is interconnected and does not depend on other teaching materials. 4) It is interactive, adapting to technological advancements and is accessible on both Android and iOS devices. 5) It allows students to perform self-evaluation using quiz questions and formative tests.

The results also finding the learning steps for the RME-based e-module consist of five stages: 1) Introducing the E-module and Contextual Problems: The lecturer provides a general overview of the e-module’s components, gives an apperception, and explains the function

material using contextual problems in the form of image and animated video. 2) Guiding Horizontal Mathematization: Students are guided to perform horizontal mathematization (critical thinking) before moving on to vertical mathematical solutions (using mathematical concepts). 3) Encouraging Independent and Group Work: Students are encouraged to solve contextual problems independently with their groups using their existing prior knowledge. 4) Facilitating Discussion with GeoGebra: Students engage in discussions about the contextual problems, assisted by a “HELP” column that is linked to GeoGebra. 5) Formulating Conclusions and Self-Evaluation: With the lecturer’s help, students create a definitive conclusion based on their evaluation results and then attempt to answer interactive quiz questions using Google Forms.

A suggestion for other researchers is that the learning material developed in this e-module is limited to the topic of functions. For interested education practitioners, they can develop RME-based e-module learning with the same learning approach or other topics to make it more interactive and also adapted to the characteristics of the students.

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