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Development of STEM Based Physics E-Modul with Virtual Lab to Improve Learning Outcomes

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AbstractThe Merdeka curriculum organizes the physics subject into concept understanding and science process skills. However, based on interviews and observations at MAN IC Pekalongan, the development of process skills in physics learning is rarely facilitated due to the limited availability of learning media and time. This RnD research aims to develop digital learning media as an alternative solution to these problems. The analysis of learning media needs showed that teachers and students need Interactive E-Modules as learning media, applications of physics in everyday life such as STEM, and a Virtual Lab packaged with interactive and simple language. The E-Module was validated by several experts in material, learning media, and learning and was declared highly feasible with an average score of 4.5 out of 5. The posttest results showed an average score of 59.67 for both the experimental and control classes. The n-gain analysis demonstrated that the E-Module effectively improved conceptual understanding, with an n-gain value of 0.74 (high), and had a positive effect on process skills with an average value of 87.86 for the experimental class and 86.44 for the control class, with a significance value of 0.032 in the independent sample test of both classes.

Keywords: E-Module, STEM, Virtual lab, Conceptual understanding, Process skills

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Introduction

Physics is a branch of natural science that studies the properties of matter in space and time, as well as related concepts of force and energy. The learning process of physics is designed to cultivate scientific reasoning, critical thinking, and problem-solving abilities in students, thereby facilitating the development of the Pancasila learner profile. The Physics Learning Outcomes in Merdeka curriculum are organized into two categories: Physics Understanding and Process Skills (Indonesian Ministry of Education, Culture, Research and Technology, 2022).

In general, students are able to apply concepts and principles in various problem-solving contexts and demonstrate the application of physics concepts in everyday life. The process skills, which are scientific and engineering skills, include the following: observing, questioning, predicting, planning and conducting investigations, processing and analyzing data and information, creating, evaluating and reflecting, and communicating results (Indonesian Ministry of Education, Culture, Research and Technology, 2022).

The results of interviews and observations with Physics teachers at MAN Insan Cendekia Pekalongan indicate that the understanding of concepts in Physics is well-developed, but the development of process skills is less emphasized. This is due to the constraints of time and the limited availability of teaching aids and laboratory equipment. Furthermore, the physics textbook employed does not elucidate the practical applications of physics concepts in everyday life.

As Ruhimat (2021) notes, the achievement of learning outcomes is influenced by a number of external and internal factors. One of the external factors that can influence learning outcomes is the quality of teaching materials. In conjunction with the accelerated advancement of science, technology, and engineering, the curriculum must be capable of evolving in order to align with contemporary developments. In order for teaching materials to play an important role in the learning process, they must develop dynamically in order to be able to adapt and anticipate developments that will occur in the future. This is in accordance with the view expressed by Asi (2017) that teaching materials are a component.

Based on this background, research is needed to develop teaching materials as an effort to improve learning outcomes consisting of concept understanding and process skills. Several studies have been conducted to improve learning outcomes. Munandar (2019) reported that the STEM learning model is effective in improving learning outcomes and student motivation. Irfana (2022) also reported that Android-based STEM learning media effectively improved critical thinking skills with an n-gain value of 0.77 (high category). Meanwhile, Rohim & Ellianawati (2020) based on their research reported that the Phet virtual lab can improve concept understanding. Benta & Wiyanto (2024) conducted research on the effect of blended learning using Phet virtual lab to improve concept understanding and found that blended learning with Phet was more effective than conventional learning.

In this study, there are several differences with previous studies, namely this learning media combines STEM-based learning with virtual experimental activities using Ophysics. This learning media is arranged in the form of a more interactive E-Module.

STEM has emerged as a key priority in national education programmes across the globe (Kelley & Knowles 2016). Erdogan and Ciftci (2017) further elucidate that the STEM approach is capable of enhancing 21st-century competencies. A virtual lab is a digital-based process simulation that enables the description of reactions that are impossible to observe in real practice. The utilization of virtual laboratories offers a number of advantages, including enhanced efficiency in terms of both time and financial resources. Furthermore, the integration of virtual laboratories into the learning process has been demonstrated to facilitate the development of essential skills, such as scientific process skills, creativity, concept mastery, motivation, and interest in the field of physics (Meiliana, 2023). The utilization of a physics virtual lab has been demonstrated to have a significant effect on students' mastery of concepts and science process skills (Ratnasari, 2023). Furthermore, the integration of virtual laboratories with STEM can enhance students' scientific literacy (Ismail, 2016). Furthermore, the utilization of virtual laboratories has been demonstrated to facilitate the acquisition of science process skills and elicit a positive response (Yusuf, 2018).

The findings of the literature review will inform the development of STEM-based e-modules, which will be supported by virtual laboratories, with the objective of enhancing learning outcomes. The outcomes of the development of this educational material can be utilized as a reference by students and educators in the field of physics.

Methods

This research employed the ADDIE model, which comprises five stages: analysis, design, development, implementation and evaluation (Mulyatiningsih, 2021). The initial stage of the process, designated as the analysis stage, entails the evaluation of the requisite characteristics of the teaching materials from the perspectives of both students and instructors. This was achieved through the utilization of a Likert scale questionnaire. The second stage, namely the design stage, entailed the creation of a design in accordance with the identified characteristics of the teaching materials, as determined by the aforementioned needs analysis. The third stage (development) entailed the creation of e-modules in accordance with the requisite characteristics, following which the product were subjected to assessment and validation by experts in the fields of materials, media, and learning media. This process informed any necessary revisions to the product. Stage 4 (Implementation) entailed the deployment of the developed product to the control and experimental sample groups. This facilitated the determination of the impact of the E-Modul and the assessment of user response to it. The fifth stage (Evaluation) was concerned with the assessment of the effectiveness of the E-Modules. This was achieved through the use of t-tests and n-gain tests. Furthermore, the researchers undertook final revisions to the product.

The objective of this research is to develop STEM-based physics e-modules assisted by virtual lab resources with the aim of enhancing conceptual understanding and science process skills. The subjects of this study were 11th grade students at MAN Insan Cendekia Pekalongan.

This research instrument was comprised of the following elements: The research instrument includes a series of questionnaires designed to elicit information from students and physics teachers regarding the teaching materials that they believe are needed. In addition, questionnaires have been developed by experts in the field of e-learning, media, and learning theory to assess the quality and feasibility of e-modules. Pretest and posttest instruments have been created to evaluate the impact of e-modules on experimental and control classes. Finally, student process skills assessment instruments have been developed to measure the effectiveness of students' learning processes.

The questionnaire employed a Likert scale, with a score of 1-5 for the categories "strongly disagree," "disagree," "neutral," "agree," and "strongly agree," respectively, to the statements in the questionnaire. The questionnaires were analysed using average scores and descriptive analysis. The reliability and validity of the questionnaire instrument were analysed using a reliability analysis on the SPSS software.

The normality of the pretest and post-test results was analysed using the non-parametric test, one-sample k-s, on the SPSS software. The decision was made that the data was normally distributed if the significance value was less than 0.05. The homogeneity of the pretest scores from both classes was analysed using one-way ANOVA on SPSS. The decision was made that the two groups were homogeneous if the significance value was below 0.05. The results were deemed to be statistically significant at a level of 0.05 or above. The difference between the experimental and control classes was analysed using the t-test on SPSS, with the decision that the two groups are significantly different if the sig value is less than 0.05. The significance level was set at 0.05. (Sujarweni, 2020). The enhancement in concept comprehension was evaluated utilising the Normalised Gain formula as proposed by Hake (1999).

$$\langle g \rangle = \frac{\%<posttest> - \%<pretest>}{100 - \%<pretest>} \tag{1}$$

The categorization of Normalized Gain results can be seen in Table 1.

Table 1. N-gain category

Interval	Category
$\langle g \rangle \geq 0{,}7$	high
$0{,}7 > \langle g \rangle \geq 0{,}3$	medium
$\langle g \rangle < 0{,}3$	low

Results and Discussion

Stage 1 (Analysis)

The data required for the needs analysis of teaching materials were collected through the use of a Likert scale questionnaire. The respondents to the questionnaire were 13 physics teachers at MAN Insan Cendekia throughout Indonesia and 71 students at MAN Insan Cendekia Pekalongan.

The results of a needs analysis of teaching materials for 13 physics teachers from various MAN Insan Cendekia institutions across Indonesia indicate that while teachers tend to prioritize concept understanding over process skills, they recognize the importance of balancing these two areas in their instruction. Furthermore, teachers believe that STEM-based learning is highly suitable for the 21st-century classroom. Furthermore, teachers concur that virtual laboratories can facilitate the illustration of abstract physical science concepts in learning.

A needs analysis of teaching materials for MAN Insan Cendekia Pekalongan students indicated that although students had physics textbooks that are relatively easy to understand and interesting to read, most students (72%) experience difficulties in learning physics for several reasons. Furthermore, students reported that virtual experiments facilitate their comprehension of physics concepts. Furthermore, students expressed interest in discussions pertaining to the applications of physics in everyday life and STEM (science, technology, engineering, and mathematics).

In the questionnaire analysis of the needs of teaching materials to students, researchers also inquired about the obstacles encountered by students when learning physics. The questionnaire revealed that students encounter difficulties in comprehending the fundamental principles of physics due to the lack of clarity, breadth, and applicability in the explanations provided in textbooks and by instructors. Furthermore, students perceive the existing physics textbook as inflexible and formal, with a lack of coherence in the explanation of the decline of the formula, and a persistently inadequate illustration. Consequently, despite the fact that students have demonstrated comprehension when instructed by the teacher, they are unable to respond effectively to higher-order thinking questions (HOTS) with cognitive levels C-4, C-5, and C-6 (Bloom's Taxonomy).

Zega (2024) posits that the capacity for high-order thinking can be enhanced through the utilization of a problem-solving learning model. Conversely, Kang (2019) posits that integrated STEM generally employs real-world problems as a learning context, wherein students utilise their knowledge and skills from various disciplines to resolve these problems. In accordance with this, Ruhimat (2021) posits that the problem-based learning model will provide an invaluable and meaningful learning experience for students. This is because, during the learning process, students are not merely passive recipients of knowledge; rather, they are actively engaged in seeking and collecting knowledge, information, and data relevant to the study of teaching materials in order to predict or answer problems as an alternative to solving problems.

There is a correlation between the STEM learning model, problem-solving abilities, and the comprehension of concepts. The STEM learning model offers students a number of benefits, including the development of a range of abilities. These include problem-solving skills, discovery skills, the capacity for innovation, independence, logical thinking, technological proficiency and the ability to apply knowledge in the workplace (Sanders, 2009). Khaira (2018) additionally posited that, based on her research, the Problem Based Learning learning model is more effective than the lecture model for improving understanding of physics concepts. In accordance with this, Supahar and Widodo (2020) have demonstrated that PBL learning with Virtual Lab is an effective method for enhancing students' science literacy and problem-solving abilities. The results of the needs analysis indicated that some students experienced difficulty in problem-solving.

The results of the needs analysis and the literature study indicate that the characteristics of teaching materials required by teachers and students are those that are systematic and interactive, presented in a communicative and easy-to-understand language. Furthermore, teaching materials are also expected to present appropriate illustrations, explain the derivation of formulas in a clear and concise manner, demonstrate the application of physics to everyday objects, incorporate STEM elements, and be equipped with virtual laboratories. In order for students to be able to study teaching materials independently at any time and in any location.

The utilization of module-type teaching materials is particularly well-suited to this context, as modules represent a systematic unit of teaching material that students can learn independently. Moreover, the provision of unambiguous and progressive instructions, which do not necessitate the involvement of an educator throughout the learning process, renders them an optimal selection (Pusdiklat Perpusnas, 2023). Moreover, modules can facilitate student autonomy and motivation to learn (Saparuddin, 2022). It is therefore anticipated that the use of module-type teaching materials will facilitate the overcoming of time constraints, as students will be able to continue their independent learning outside of the classroom if there is insufficient time during the learning process. One potential solution to the limitations of practicum tools is to utilise virtual laboratories that are available on the internet, such as Phet, Ophysics and others. Furthermore, in order to facilitate students' process skills and the completion of Higher Order Thinking Skills (HOTS) questions, the module also requires problem-solving-based activities.

Stage 2 (Design)

E-module design refers to the characteristics of teaching materials that are required by teachers and students. The E-Module structure comprises two distinct types of pages: the Home page and the Material page. The home page provides an overview of the e-module, instructions for its use, and guidance on learning physics. The Material page comprises learning objectives, learning outcomes, apperception, a table of contents, core material presented with the STEM approach, a virtual lab, problem-solving-based activities, competency tests using a quiz and bibliography. On the material page, a narrator functions to guide students in their learning. The material page in this study is limited to the Dynamic Fluid material, with the objective of determining the characteristics of an effective e-module. The results of this study will be used as guidelines in the preparation of e-modules with other materials.

Stage 3 (Development)

The characteristics of the requisite teaching materials have been taken into account in the design of the E-Modules, which are delivered via web media. This format offers several advantages, including greater practicality, interactivity, and the ability to incorporate a multitude of features, such as images, animations, videos, and virtual laboratories (Karyati, 2023; Meduri et al., 2022). Another advantage is that the preparation and distribution costs are relatively lower compared to printed modules, as the content can be accessed through laptop, tablet, or smartphone devices without the need for installation of an application.

The most widely used virtual lab today is Phet. Nevertheless, the Phet virtual lab lacks a simulation of dynamic fluids, necessitating the use of the Ophysics simulation in the E-Module virtual lab. Fluid Dynamics and the Bernoulli Equation (source: https://ophysics.com/fl2.html) can be displayed directly (embedded) on the E-Modul page and equipped with LKPD.


DAFTAR ISI

Berikut adalah daftar isi pada Bab Fluida Dinamis, silahkan klik text daftar isi berikut ini untuk menuju ke sub bab yang kamu ingin pelajari

- Tujuan Pembelajaran
- Materi
  1. Debit dan Asas Kontinuitas
  2. Daya oleh Debit
  3. Prinsip Bernoulli
     - Efek Venturi
     - Virtual Experimen
     - Penurunan Persamaan Bernoulli
  4. Aplikasi persamaan Bernoulli
     - Pesawat Terbang
     - Tabung pitot
     - Formula 1
     - Teorema Torriceli
     - Siphon

Figure 1. Table of contents view (initial / before revision)

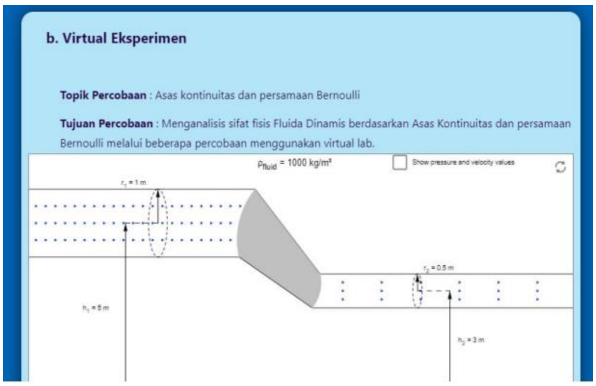

Figure 2. Virtual lab view - Ophysics (initial / before revision)

Example and practice questions are presented in pdf file format which can be viewed in a new tab so that they can be downloaded. The video illustrations are sourced from relevant YouTube which can be displayed directly (embedded) on the E-Module page. While the competency test uses Quiziz media as an evaluation tool because it has several advantages. Quiziz is an educational game application that can be used to deliver material and evaluation media, the advantages of quizizz as an evaluation media are that it has an attractive and interactive appearance, is able to train students to manage question processing time, allows students to compete with each other for the best score so that it can increase student motivation in doing questions (WD et al. 2022) (Munjaidah et al, 2021). The initial E-Module display can be observed in Figures 1, 2, 3, and 4.

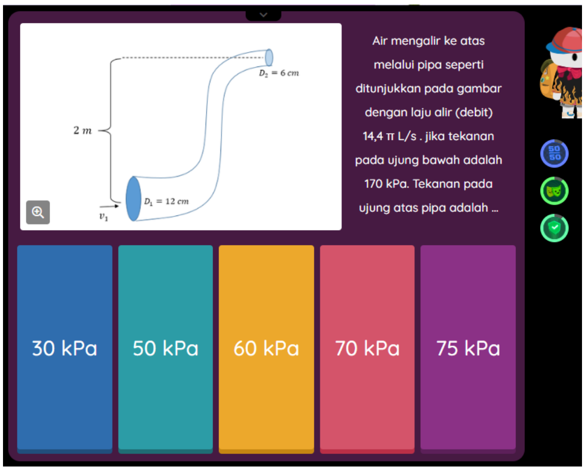

Figure 3. Evaluation view - Quiz (initial/before revision)

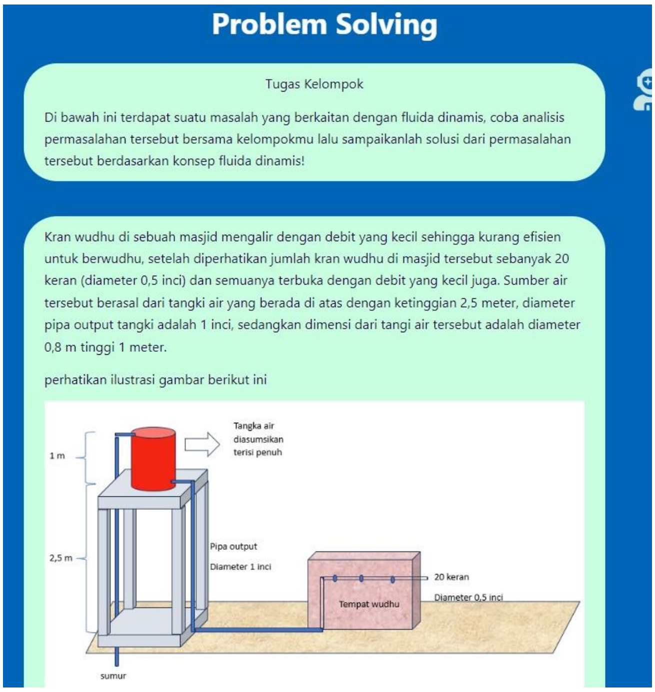

Figure 4. Problem solving view (initial/before revision)

The prepared e-modules were then evaluated and validated by 2 material experts, 2 media experts and 2 learning experts. The validation results by experts are shown in Tables 1, 2 and 3. The material expert validation tool consists of 13 questions that can be grouped into 3 aspects. The results of the material expert validation are shown in Table 2.

Table 2. Material expert validation score

Aspects	Average score	Category
Material Quality	4,5	very good
Accuracy of Material	4,3	very good
STEM suitability	4,25	very good

Table 2 presents the overall score results, which can be calculated as an average of 4.35 (very good category). However, revisions have been made based on suggestions from validators. These include revising some symbols that were less consistent, revising the order of presentation of material to be more systematic, revising some material that was less precise with physics concepts, adding narratives to decrease the number of equations, and deepening and expanding STEM (Science, Technology, Engineering, Mathematics) elements.

The Media Expert Validation Instrument was comprised of 14 questions, which can be classified into three principal categories (aspects). The results of the media expert validation can be observed in Table 3.

Table 3. Media expert validation score

Aspects	Average score	Category
Lay-out Design	4,5	very good
Ease of use	4,9	very good
Consistency and suitability	4,7	very good

Table 3 presents the overall score results, which average at 4.7 (very good category). However, revisions were necessary, including the rewriting of image codes and the addition of a learning flow at the beginning of the material. The learning expert validation instrument comprises 10 questions, which can be grouped into five distinct aspects. The results of the learning expert validation can be observed in Table 4.

Table 4. Learning expert validation score

Aspects	Average score	Category
Suitability with learning objectives	5	very good
Ease of use	4,5	very good
Systematically organized	4	good
STEM suitability	5	very good
Able to stimulate students to develop process skills	4,4	very good

The overall score for Table 4 can be calculated as an average of 4.58, which falls within the very good category. However, minor revisions were necessary to correct some writing errors. The following is a display of the E-Module following revision by the validator, as illustrated in Figure 5 and Figure 6).

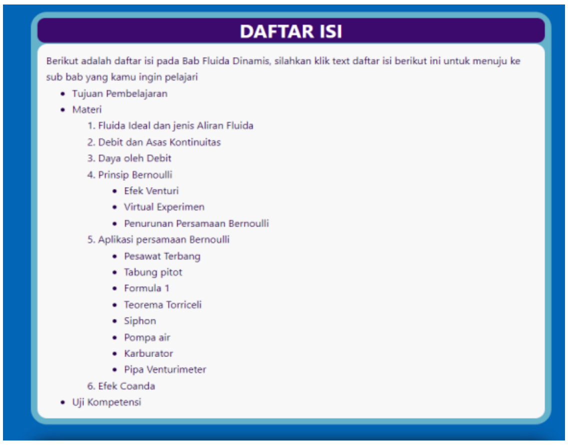

Figure 5. Table of contents after revision from validators

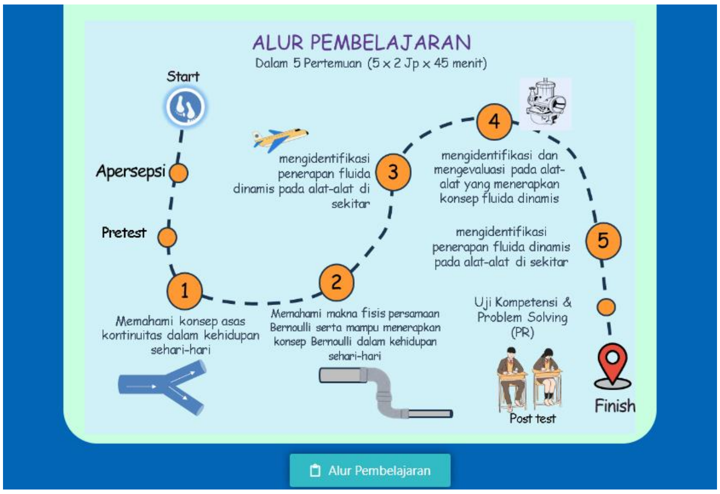

Figure 6. View of learning flow addition after revision from validator

1. **Stage 4 (Implementation)**

The revised e-module, which had been subjected to expert validation, was implemented in the teaching of physics on the topic of dynamic fluids in both experimental and control classes over a period of five meetings. The experimental class comprised 24 students, while the control class also had 24 students..

At this stage, researchers applied the E-Module to the experimental class in learning, while the control class still used conventional textbooks. Before and after learning both classes were given pretest and posttest questions to determine the increase in concept understanding. In addition, in the learning process, researchers also observed and assessed process skills to determine differences in process skills in experimental and control classes.

At this juncture, the researchers initiated the implementation of the E-Module in the experimental learning class, while the control class continued to utilise conventional textbooks. Prior to and following the learning period, both classes were administered pre- and post-test questions, respectively, to ascertain the extent of conceptual understanding gained. Furthermore, the researchers observed and assessed the process skills of the students in both the experimental and control classes during the learning process..

2. Stage 5 (Evaluation)

At this juncture, researchers conducted an analysis of the Pretest, Posttest, and Process Skills of students during the learning process. This analysis was undertaken with the objective of determining the effectiveness of the use of E-Modules in improving the understanding of concepts and the acquisition of science process skills. Figure 7 presents the pretest scores of the experimental and control classes.

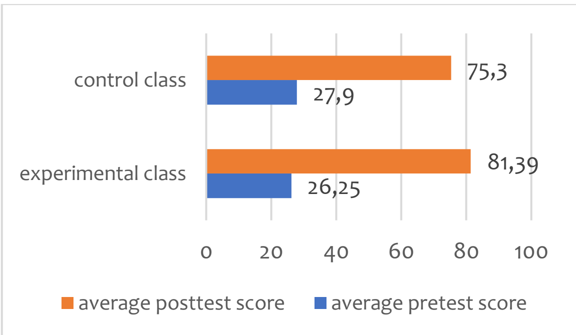

Figure 7. Pretest-posttest scores of experimental and control classes

The results of the pre-test for the experimental class were found to be normally distributed, with a significance value of 0.245. Similarly, the control class pre-test results were also normally distributed, with a significance value of 0.277. The homogeneity test of the two classes demonstrated that both were homogeneous, with a significance value of 0.510.

After learning the core material, both classes did the post-test questions. Based on the t-test analysis using SPSS, it shows that there is a difference with a sig value of 0.042. The increase in concept understanding value was analysed using Normalised Gain and it was found that the value of <g> in the experimental class was 0.74 (high category). While the control class obtained a value of 0.45 (medium category). Comparison of N-Gain values between experimental and control classes can be seen in Figure 8.

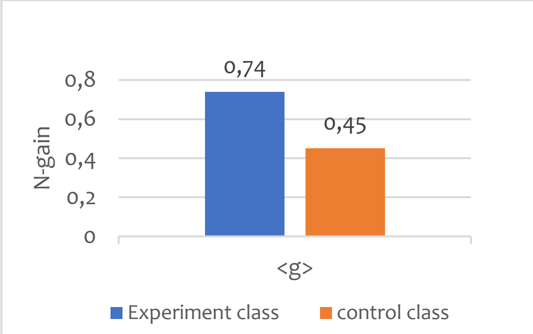

Figure 8. Comparison of n-gain values

The findings of this study indicate that the developed E-Module is an effective tool for enhancing students' understanding of the concepts under study. The results of this study are also supported by several previous studies. Sandi (2021) discovered that the STEM approach is an effective method for enhancing comprehension of electroplating concepts, fostering critical thinking abilities, and promoting collaborative learning. In her literature review, Khaira (2018) also identified that STEM learning can enhance motivation, knowledge, innovation and creativity.

Byukusenge et al. (2022) posited that virtual laboratories are generally efficacious in the teaching of challenging and abstract topics. Benta and Wiyanto (2024) demonstrated that blended learning with the incorporation of virtual laboratories is an effective method for enhancing conceptual understanding. Furthermore, Rohim and Ellianawati (2024) demonstrated that the utilization of virtual laboratories can enhance the comprehension of concepts and stimulate student motivation.

The Process Skills Assessment was divided into six distinct aspects, which are presented in a sequential order. These aspects are as follows: (1) observing; (2) questioning and predicting; (3) planning and conducting investigations; (4) processing and analyzing data and information; (5) evaluating and reflecting; (6) communicating results. The results of the process skills assessment are presented in Figure 9.

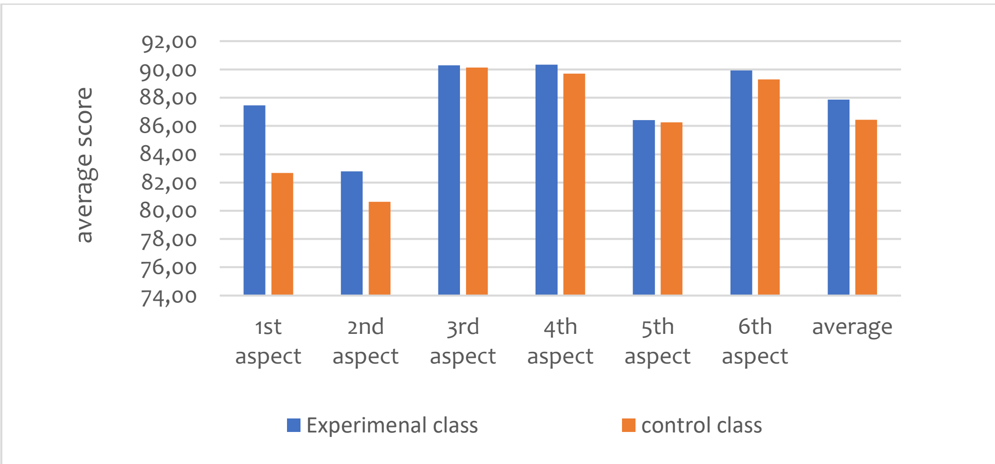

Figure 9. Process Skills Assessment

The average value of process skills in the experimental class is higher than the control class, which is 87.86 for the experimental class and 86.44 for the control class. Independent sample test analysis (using SPSS) of the average value of process skills in all aspects shows that there is a difference in the value of process skills between the experimental and control classes with a sig value of 0.032..

This study showed that learning with the E-Module that had been developed was effective for improving concept understanding with an n-gain value of 0.74 (high category). In addition, the results of this study also showed that there was a difference between the understanding of the concept of E-Module users and the understanding of the concept of conventional book users with a sig value on the independent sample test SPSS is 0.042.

A questionnaire had been distributed to experimental class students to ascertain their responses to the e-module. The user response questionnaire score can be found in Table 5. Further insight into the stimulation of process skills can be gained from Table 6.

Table 6 . User response questionnaire score on the aspect of stimulating process skills

No	Aspect	Average Score	Category
1	Observing	4,4	Very good
2	Asking questions and predicting	3,9	good
3	conducting investigations	4,1	Very good
4	process and analyse	4,1	Very good
5	conducting evaluations	4,0	Very good
6	communicating results	3,9	good

Students have proposed a number of improvements to the online learning environment, including enhancing the visual appeal of the website to make it more engaging and up-to-date, providing downloadable materials, offering a greater variety of example problems, incorporating learning videos on topics such as formula reduction and problem discussion, and including video links as an alternative if the video cannot be played on the E-Module. The researcher then proceeded to implement several revisions in accordance with the suggestions put forth by the students. The revised E-Module can be accessed at https://edu-phy.my.id/.

The results of the analysis of the process skills of experimental and control class students demonstrated a statistically significant difference between the two classes, with a value of sig (2-tailed) is 0.33. The experimental class exhibited a superior average score compared to the control class. This is consistent with the findings of Zainuddin's (2022) research, which demonstrated that STEM-based LKPD teaching materials can enhance students' science process skills. Nevertheless, the value of process skills (Figure 9) in aspect 2 (questioning and predicting) is the lowest of all aspects, with a value of 82.8. These results are also consistent with the value of the user response questionnaire by students (Table 5), which indicates that this aspect received a relatively lower average score than other aspects, namely 3.9, which falls within the "good" category. Similarly, in the context of evaluating and reflecting, the average value of 86.4 is below the overall average of 87.9 (see Figure 9).

Based on the results of this study, E-Module can be declared effective in improving conceptual understanding with an n-gain value of 0.74. This is because in the E-Module students are guided to find, develop, and apply the concepts that have been learned. However, this study still has limitations, namely not identifying 4 indicators of conceptual understanding, namely the ability to define concepts, recognize concept characteristics, relate concepts to other concepts, and identify or provide examples of the concept (Eggen & Kauchack, 2012) in detail

The process skills of students in the experimental and control classes showed a difference between the two classes with a sig value of 0.32 where the experimental class got a better average score than the control class. These results are also relevant to the conceptual understanding value of the experimental class which is superior to the control class. Based on the research results of Sari et al. (2018) there is a correlation between conceptual understanding and science process skills. Science process skills and conceptual understanding complement and strengthen each other, a strong conceptual understanding will make it easier for students to develop science process skills. Conversely, by mastering science process skills, students can build better conceptual

It is recommended that teachers create learning objectives at each meeting that align with the learning outcomes. This allows students to understand the learning targets and objectives at each meeting. Additionally, teachers should strive to create an interactive and controlled classroom atmosphere. In addition, students are encouraged to proactively inquire about any concepts or tasks that remain unclear during the learning process. This approach fosters a sense of accountability and responsibility for the assigned tasks.

Conclusion

The results of the needs analysis indicate that students and teachers require teaching materials that possess a number of characteristics. The aforementioned characteristics include the following: interactive, presented in communicative language and easy to understand, accompanied by appropriate illustrations, explaining the derivation of formulas with easy-to-understand narratives, showing the application of physics to things around students, showing STEM, and there is a virtual lab. Furthermore, students require supplementary material in the form of videos or e-modules that can be downloaded as alternative teaching materials. The analysis of learning outcomes in classroom implementation revealed that the STEM-based e-module assisted by a virtual lab effectively improves concept understanding with an N-gain value of 0.74 (high category) and produces better process skills than using conventional textbooks. So this E-Module can be used as a reference for classroom learning. In addition, researchers or teachers can adapt the structure and characteristics of this E-Module to other topics.

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