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Integration of Palembang LRT in the E-Module for Alternating Current Electricity STEM: A Study of Validity, Practicality, and Effectiveness

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Abstract: This study aims to develop a STEM-based alternating current electricity e-module integrated with Palembang local wisdom, and to test its validity, practicality, and effectiveness. The development method used is the 4D model, which includes the defining, designing, developing, and disseminating stages. Validation activities involved nine experts, while the trial was carried out in two stages, namely a limited trial with nine students and a broad trial with eighteen students of grade XII. The validation results, all of which were classified as valid to very valid. In the practicality test, the ease of use aspect reached a very practical category, as did the display design and the presentation of material and benefits, all of which were in the very practical category. The highest improvement was obtained in the elaboration indicator, as the e-module provided open-ended problems that encouraged students to use imagination and reasoning in solving them. At the dissemination stage, the developed product was distributed through Google Sites so that it could be easily accessed by students and teachers. Thus, the STEM-based e-module is declared valid, practical, and effective for use as innovative learning media relevant to both the Alternating Current Electricity topic and the context of the Palembang LRT.

Keywords: Effectiveness; E-Module; Light Rail Transit; Physics; STEM

Introduction

Physics is a branch of natural science that focuses on studying matter, energy, and the interaction between the two, which is closely related to various natural events and phenomena. Through physics learning, students can understand and explain various natural events that occur in the surrounding environment, making this science very relevant to everyday life (Jankvist & Niss, 2019; Osborne, 2021; Tytler, 2022). Physics learning not only aims to understand basic concepts, but it also emphasize the development of essential skills such as problem solving, critical thinking, and creative thinking. These skills are part of the 21st-century competencies that are needed by students (Farjon et al., 2019; Qian & Huang, 2020). In this modern era, the demand for critical thinking, creativity, and problem-solving skills is increasing (Azhary & Wiyono, 2020; Liu et al., 2022; Wang et al., 2020). By mastering these skills, students can analyze information in depth, create innovative solutions, and apply physics concepts in the context of real life, so that they are ready to face complex challenges in the future (Harris & Jones, 2019). Therefore, physics learning plays a crucial role in equipping students with the 21st-century skills needed to succeed in an ever-evolving world.

21st-century skills include four main aspects, namely Critical Thinking, Creativity, Communication, and Collaboration (Sativa et al., 2022; Yuliana et al., 2023). These skills are important provisions that students must master to face the challenges of modern life, especially in terms of creative thinking. However,

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various studies show that the average score of students' creative thinking skills is still at 28.53%, which is included in the less creative category. This finding indicates that students have not been able to fully develop high-level thinking skills optimally. Students tend to provide only one solution when answering questions, which indicates that the aspects of fluency, flexibility, and originality in creative thinking still need to be improved (Mixsen et al., 2024). Creative thinking is prioritized among 21st-century skills because it underpins other competencies, preventing critical thinking from becoming rigid, communication from being less innovative, and collaboration from lacking novelty (Henriksen et al., 2021; Susilawati et al., 2021). It is closely tied to generating ideas, problems solving, and adapting to rapid changes, so strengthening creativity also drives the integrated development of all 21st-century skills.

Creativity in learning plays an important role in increasing student activeness, building self-confidence, encouraging participation in discussions, and helping students solve problems and take advantage of existing opportunities (Ritter et al., 2020; Sawyer & Sawyer, 2021; Susilawati et al., 2022). In Indonesia, physics learning needs to be oriented to toward students' creative thinking skills, in line with the principles promoted by the Merdeka Curriculum (Ambo & Keong, 2021; Azairok et al., 2023). The Merdeka Curriculum emphasizes that the development of creative thinking skills in physics learning is very important, not only to deepen students' understanding of physics concepts, but also to encourage them to generate new ideas and innovative solutions for solving problems (Ananiadou, 2020; Prasetyo et al., 2020). To achieve these goals, it is necessary to support quality teaching materials, such as e-modules, which can be an effective medium for training students' creative thinking skills.

E-Modules are learning media that are systematically designed to facilitate students in learning independently without relying entirely on direct guidance from the teacher. In addition, e-modules can also be adjusted to the speed of student learning, especially for those who have the ability to learn faster (Bai et al., 2019; Xia et al., 2021). The development of e-modules is currently increasingly leading to the integration of local wisdom, so that learning materials are more relevant and close to students' lives. By linking physics learning through local wisdom, students can understand physics concepts by seeing their application in their daily lives and culture. This makes it easier for students to connect physics theories with the real context and culture they are familiar with (Mahyuddin et al., 2025; Sari et al., 2025). Therefore, e-modules need to be designed with clearly structured approaches and principles to achieve learning objectives effectively (Dlouhá, 2022; Liu et al., 2022).

One of the structured and clear approaches is the STEM (Science, Technology, Engineering, and Mathematics) approach (Karwowski et al., 2020). This approach is in line with the principles of STEM education, which integrates science, technology, engineering, and mathematics with real-life contexts, thus encouraging students to solve problems based on the surrounding environment (Ismet et al., 2022; Maslin et al., 2023; Mauritz et al., 2024). The STEM approach is considered one of the learning methods that best fits the 21st-century education standards (Hasih Nurhayati et al., 2024; Henriksen et al., 2020). In a rapidly evolving era, the younger generation is faced with increasingly complex and multidisciplinary challenges. Therefore, the STEM approach is the right solution to meet the demands of modern education, preparing students to face problems that are not limited to one field of science alone.

Its implementation in the field is still hampered by the limited availability of innovative teaching materials that are capable of integrating the STEM approach with an authentic local context. This study responds to these challenges through the development of a STEM-based alternating current electricity e-module integrated with Palembang's Light Rail Transit (LRT) technology. The novelty of this study lies in the integration of three key elements: the abstract concept of AC electricity, a structured STEM approach, and the context of Palembang's LRT technology as a representation of modern local wisdom. The importance of this research is supported by three fundamental arguments: first, a needs analysis shows that students need contextual teaching materials; second, there is a research gap in that there are no physics e-modules that comprehensively integrate STEM with Palembang's LRT; third, there is a pedagogical urgency to bridge the abstract concept of AC electricity with meaningful learning experiences through case studies of modern transportation technology.

Several studies related to the development of STEM-based e-modules and local wisdom have been conducted, resulting in e-modules that are valid, practical, and effective in improving students' creative thinking skills (Karwowski et al., 2020; Sari et al., 2023). However, until now there has been no research that develops STEM-based e-modules with the context of the wisdom of the Palembang Light Rail Transit (LRT) which refers to the Merdeka Curriculum to train students' creative thinking skills. The novelty of this study lies in integrating STEM learning with the specific context of Palembang LRT, which not only represents a local cultural and technological identity but also serves as a real-world phenomenon directly connected to

physics concepts. This combination is important because it contextualizes abstract electrical materials into students' daily experiences, thereby enhancing engagement and relevance (Nazhifah et al., 2022; Sari et al., 2025). At a broader level, this research fills the knowledge gap in linking STEM-based e-modules with local wisdom within the framework of the Merdeka Curriculum, an approach that has rarely been explored in Indonesian physics education research (Wiyono et al., 2025). Based on the needs analysis, 94.4% of students stated the need for the development of STEM-based physics e-modules that integrate the wisdom of the Palembang Light Rail Transit (LRT). Therefore, this study aims to develop a STEM-based physics e-module with the context of the wisdom of the Palembang Light Rail Transit (LRT) that is valid, practical, and effective as an e-module.

Method

Participants

This research was conducted from January to May 2025. The participants consisted of involving 9 experts validators (3 subject matter experts, 3 media experts, and 3 language experts), and 9 grade XII students in the limited trial stage, and 18 grade XII students in the broad trial stage. The students were selected using purposive sampling, since the chosen class was studying the Alternating Current Electricity topic, which was directly relevant to the e-module content. The selection of participants was based on the relevance of the material, the availability of time, and accessibility. A potential limitation of this study is the relatively small sample size, which may affect the generalizability of the findings. Therefore, the emphasis of this research is on the internal validity of the developed product rather than broad generalization.

Research Design and Procedures

This study employed a research and development (R&D) design using the 4D model, consisting of Define, Design, Develop, and Disseminate (Asyhari & Diani, 2017; Hamid, 2021). This development model was chosen for the development of teaching materials because this model is designed systematically and comprehensively, making it suitable for producing effective and quality learning products, especially for e-module teaching material development products (Azzahra et al., 2022). The research procedures were as follows:

Define: needs analysis was carried out through curriculum review, content analysis, and analysis of student characteristics. Design: the initial design of the digital e-module was developed according to the identified needs.

Develop: expert validation was conducted on three aspects, namely content, media, and language. Concrete inputs from validators included improving consistency of physics terminology, adjusting font size for better readability, and refining grammar. Inputs from students in the limited trial suggested simplifying the navigation layout. All feedback was incorporated into revisions before the broad trial stage.

Disseminate: the product was tested with students from a different class and introduced to physics teachers in the partner school. Broader dissemination strategies are planned, include presenting the product at educational seminars, depositing the e-module in the school's learning repository, and encouraging adoption by other teachers through the Physics Teacher Association (MGMP). The main challenges in dissemination involve students' unequal access to digital devices and teachers' readiness to integrate e-modules into their teaching. The research flow is presented in Figure 1.

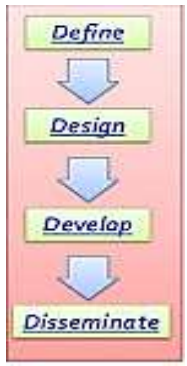

Figure 1. 4D stages

Instruments

The instruments used in this study were as follows: expert validation sheets covering content, media design, and language aspects, adapted from the National Textbook Standards (Umami et al., 2021). Content validity was ensured by involving three experts for each aspect, while inter-rater reliability was calculated using percentage agreement.

A student response questionnaire consisted of four aspects: ease of use, design and appearance, material presentation, and usefulness (Qomariyah et al., 2021). This instrument employed a Guttman scale ("Yes" = 1, "No" = 0). The Guttman scale was preferred over the Likert scale because it provides a clear dichotomous response, making it easier to measure students' acceptance or rejection of the e-module features. However, its limitation is that it does not capture the gradation of student perceptions.

Pretest and posttest essay tests were administered to assess the effectiveness of the e-module in improving creative thinking skills. The creative thinking indicators

measured included: (a) fluency: number of relevant ideas; (b) flexibility: variety of problem-solving strategies; (c) originality: novelty of answers; and (d) elaboration: completeness and detail of responses. Scoring was conducted using a rubric ranging from 0–3 for each indicator, with a maximum score of 12 per item. The structure of the creative thinking test instrument is shown in the Table 1.

Table 1. Indicators of Creative Thinking Skills Test

Indicators	Descriptions	Number of Item	Question
Fluency	Able to provide various interpretations of images, stories, or problems	2	1, 4
Flexibility	Able to plan various solutions to solve problems	2	5, 8
Originality	Giving rise to new ways of thinking	2	3, 7
Elaboration	Planning can be completed with detailed steps.	2	2, 6

Data Analysis

The data analysis technique used product feasibility analysis obtained from the average results of experts, while the analysis of student responses referred to the Guttman scale (Sugiyono, 2019). The results of expert validation based on the Guttman scale were analyzed using the formula according to Nadori et al. (2021) as follows.

$$NP_{ri} = \frac{TS_{i-e}}{TS_{i-max}} \times 100\% \quad (1)$$

Description:

i = 1, 2, 3
NPr = validator process score
i = validitor number – (1,2,3...)
$TS{-}e$ = total empirical score (score obtained from validators)
$TS{-}max$ = Maximum total score
V = Validation (Combined)

The validation results from each validator were analyzed and calculated using the formula, as stated by Nadori et al. (2021). Then grouped based on the validity criteria as presented in Table 1.

Table 2. Criteria Validity

Percentage	Criteria
81.00% - 100%	Very Valid
61.00% - 80.00%	Valid
41.00% - 60.00%	Moderately Valid
21.00% - 40.00%	Not Valid
00.00% - 20.00%	Very Invalid

Table 3. Percentage Practicality

Percentage	Criteria
0 – 20 %	Very Impractical
21 – 40 %	Impractical
41 – 60 %	Moderately Practical
61 – 80 %	Practical
81 – 100 %	Very Practical

The results of the response questionnaire used in the limited trial and broad trial stages were analyzed using percentage data from the Guttman scale, where P is the percentage of student answers, F is the number of respondents' answers, and N is the respondent's score. Then, the percentage results were grouped based on the practicality criteria according to Maghfirah et al. (2022) as presented in Table 3.

Qualitative data obtained through questionnaires distributed during limited trials and extensive trials were then converted into qualitative form by assigning scores on a Guttman scale to see students' responses to the developed e-module. The converted data was then presented in tabular form and the percentage of prototype practicality was calculated using the formula according to Kaukaba et al. (2022) as follows:

$$P = \frac{F}{N} \times 100\% \quad (2)$$

Description:
P = percentage of student responses
F = number of respondent responses
N = Score responses

Test instruments were used in the form of pretest and posttest to assess the effectiveness of the teaching materials developed. The instruments used were essay questions that were completed independently to assess students' creative thinking skills. To analyze the research data, a pretest-posttest test was conducted using the normalized gain formula as follows:

$$N - Gain\ \langle g \rangle = \frac{posttest - pretest}{high\ skor - pretest} \quad (3)$$

The gain calculation results are then interpreted using the classification shown in Table 4.

Table 4. Criteria Score N-Gain (Hake, 1998; Sativa et al., 2022)

N-Gain Score	Description
$g \geq 0.7$	High
$0.7 > g > 0.3$	Medium
$g \leq 0.3$	Low

Results and Discussion

The results of this study are STEM-based alternating current electricity e-modules in the context of Palembang Light Rail Transit (LRT) which aim to determine the results of validity and practicality. The e-module was developed in accordance with the 4D development procedure with the results of e-module development from each stagen described as follows.

Define Stage

This stage contains a beginning-end analysis, student analysis, concept analysis, task analysis and formulation of learning objectives. The results of this defining stage reveal that the Merdeka Curriculum encourages student-focused learning, giving teachers the flexibility to customize materials as needed. Mastery of 21st-century skills is essential for students so that they are able to solve problems and innovate. However, the learning tools available at school are often inadequate, causing students to tend to memorize material without understanding its application, especially in STEM-based physics learning. Seeing this situation, it is necessary to present e-modules in STEM-based physics learning associated with the context of Palembang LRT. The STEM approach integrated with the wisdom of LRT will make learning easier for students to understand. If applied in e-modules, this approach becomes very important and relevant, so it is very suitable to be implemented in learning activities (Fadillah, 2024). As many as 71.9% of students stated that they often use printed and electronic teaching materials, this is in line with previous research that teaching materials are commonly used in the form of modules, both in printed and electronic form (Santosa et al., 2025). As many as 83.1% of students find it easier to understand the material when it is associated with the context of everyday life and as many as 94.4% of students think that it is necessary to develop STEM-based physics e-modules with the context of Palembang LRT. This finding is in line with previous research that emphasizes the importance of developing STEM-based physics e-modules in the context of Palembang LRT (Amrullah, 2017; Permana, 2023; Rahadiantino, 2022). The selected physics concept is alternating current electricity material class XII, the material is mapped through concept analysis, resulting in several sub-materials arranged in the e-module and the formulation of learning objectives.

Design Stage

The results at this design stage include designing a STEM-based alternating current electricity e-module in the context of the Palembang LRT that is in accordance with the STEM approach, first preparing the instrument based on product needs and then designing a learning process activity plan for three meetings. The e-module prototype was designed starting from selecting the application to be used in this study, namely the Canva application, which was selected because it has many interesting features and makes learning more accessible and effective (Firdaus & Hamdu, 2020; Nesti et al., 2022). After this e-module was completed, it was published using the Hyzine website. In this stage, the researchers also compiled the structure of the e-module, which includes a cover, preface, table of contents, instructions, introduction, e-module description, learning activities, evaluation questions and answer keys, summary, glossary, and bibliography (Yetişensoy & Karaduman, 2024). Then produce an initial prototype in the form of an e-module, which is presented in Figure 2.

Figure 2. Prototype e-module

Development Stage

The flow of e-module development follows the validation and development test stages. The following diagram shows the development process systematically, as displayed in Figure 3.

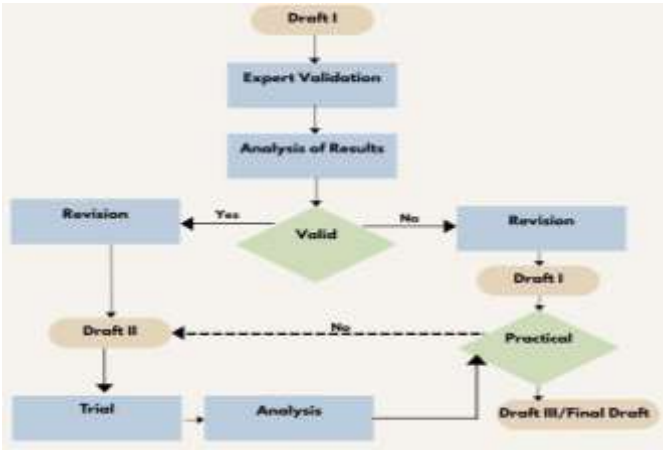

Figure 3. Flow of development stages

The analysis results obtained at the validation stage can be seen in Figure 4.

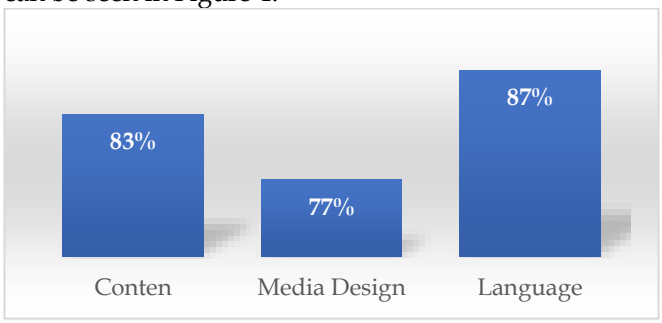

Figure 4. Validation result

The percentage of expert validation results is classified based on expert criteria according to Pratiwi et al. (2025). Based on the results at the expert appraisal or validation test stage, the percentage in the content aspect is 83% with very valid criteria, this is in line with previous research stating that the overall percentage of validity in e-modules reaches very valid criteria (Utaminingsih & Ellianawati, 2025). The percentage of media design was 77% with valid criteria, according to related research, STEM-based e-modules in the context of local wisdom need to be evaluated from various points of view, including design (Padios & Tobia, 2023). In the language aspect, it gets a percentage of 87% with valid criteria (Zhafirah et al., 2020). So overall the STEM-based alternating current electricity e-module in the context of Palembang LRT is valid and feasible to be tested (Delita et al., 2022).

The practicality test was carried out using a student response questionnaire. The practicality of teaching materials aims to assess their effectiveness in supporting student learning activities (Sofyan, 2019; Sulaiman et al., 2023). To determine, two trials were conducted, namely limited trials and broad trials. Students were given the opportunity to use or access the STEM-based alternating current electricity e-module that raises the context of the Palembang LRT. Students were asked to provide an assessment and comments regarding the e-module. The results of the assessment at the limited trial stage are shown in Figure 5.

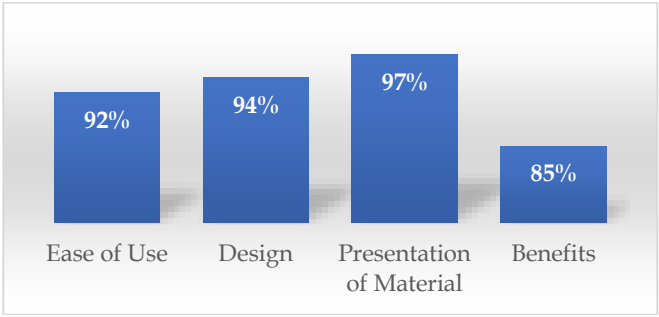

Figure 5. Results assessment limited trial

Based on the results of the assessment at the limited trial stage, the results in the aspect of ease of use were 92% with very practical criteria, in the appearance and design aspect 94% with very practical criteria, then the presentation of material was 97% also with very practical criteria, and in the benefit aspect was 85% with very practical criteria (Azriyanti & Syafriani, 2023; Khuzaimah et al., 2022; Suharno et al., 2022). So, for the limited trial, overall, the e-module was declared very practical. The students were also given the opportunity to provide input and suggestions related to the developed product. Input and suggestions from students were used as considerations in revising the products developed (Alyusfitri et al., 2024). E-modules that have been declared very practical at the limited trial stage were then continued at the broad trial stage. The results at the broad trial stage are shown in Figure 6.

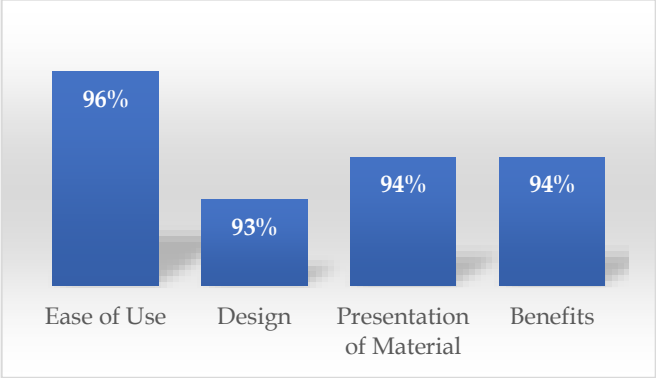

Figure 6. Results broad trial

Based on the data shown in Figure 6, the ease use aspect received a score of 96%, the appearance and design aspect received a score of 93%, the material presentation aspect received a score of 94%, and the usefulness aspect received a score of 94%. Thus, overall, the e-module received a score of very practical in all aspects. These results align with previous research indicating that this can help identify areas requiring improvement and evaluate the effectiveness of educational interventions, such as the implementation of e-modules (Yulianti & Herpratiwi, 2024). The ease of use aspect indicates that the e-module is used effectively. Tampubolon et al. (2024) emphasize that user-friendly interfaces and designs enhance user comfort. According to Mardiantiningsih et al. (2024), well-structured material presentation improves understanding. On the other hand, the benefits of the device demonstrate a tangible contribution to learning, supporting the findings (Wanabuliandar, 2023). These results indicate that the device is designed to meet user needs and can be widely used. Therefore, overall, the STEM-based alternating current electrical e-module in the context of

the Palembang LRT at this stage is highly valid and practical.

Disseminate

Based on Table 5, the pretest and posttest results showed an improvement, with the pretest yielding an average score of 39.34 and the posttest yielding an average score of 86.72, resulting in an N-Gain score of 0.75. This indicates an increase in students' scores before and after using the developed e-module. Furthermore, Figure 7 presents the N-Gain results for each indicator of students' creative skills.

Table 5. Result Pretest and Posttest

Result	Average	N-Gain
Pretest	39.34	0.75
Posttest	86.72	

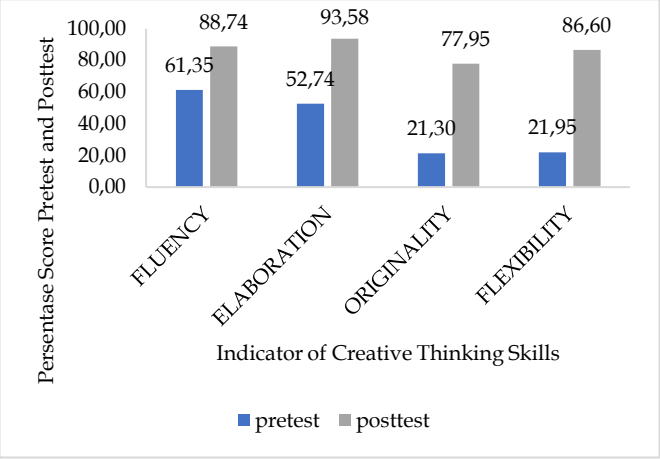

Figure 7. Result score pretest and posttest

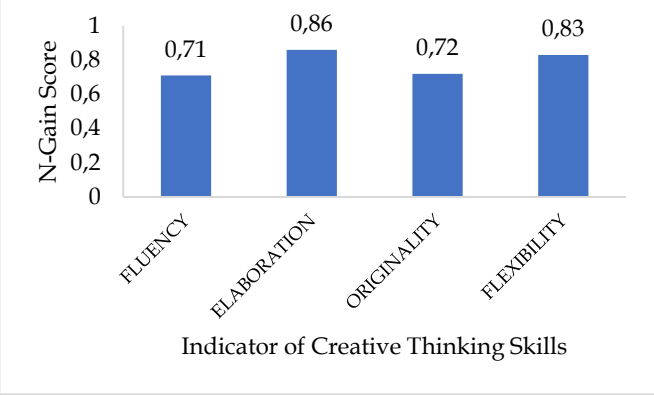

Figure 8. Result n-gain creative thinking skills

Based on the data in Figure 8 above, there are four creative skill indicators that have increased with an N-Gain value above 0.7, which can be categorized as high. Based on the data in Figure 8 above, there are four indicators of creative skills that experienced an increase with N-Gain values above 0.7, which can be categorized as high. The elaboration indicator obtained the highest N-Gain value 0.82 because the e-module provides contextualized problems and open-ended tasks that allow students to develop answers with detailed reasoning and connections to real-world scenarios such as energy efficiency analysis in the Palembang LRT system. On the other hand, the fluency indicator obtained the lowest N-Gain value 0.71 due to several key factors. Abstract concepts of alternating current electricity such as impedance and phase difference limit students' ability to generate many ideas in a limited time. Further analysis shows that 65% of students had difficulty in providing more than three alternative solutions to LRT electrical system problems, with an average response time of 4.2 minutes per question compared to only 2.8 minutes for other indicators. These findings imply that future e-module designs should incorporate more scaffolding strategies such as technical vocabulary banks, interactive phasor diagram visualizations, and structured brainstorming activities with gradual prompts to strengthen fluency while maintaining elaboration-oriented tasks. Furthermore, specific exercises in the form of ideation games are needed to improve idea generation fluency in solving complex electrical problems. In the final dissemination phase, the researcher distributed the product that had been used via Google Sites through the following link: https://sites.google.com/view/e-bahanajarfisika/home.

Therefore, during the disseminate phase, this product was piloted with students from different grades and introduced to physics teachers at partner schools. A broader dissemination strategy is planned, including product presentations at educational seminars, storing the e-module in school learning repositories, and encouraging adoption by other teachers through the Physics Teachers Association (MGMP). Key challenges in dissemination include unequal student access to digital devices and teachers' readiness to integrate the e-module into their teaching.

The development of e-modules in this study is conceptually based on the principles of Constructivism Theory, which emphasizes that knowledge is actively constructed by learners through experience and interaction with their learning environment. This e-module is designed to facilitate the process of knowledge construction through the presentation of structured yet flexible content, exploratory activities, and cognitive challenges that encourage learners to connect new concepts with their prior knowledge (Wiyono et al., 2024). In addition, elements of Cognitive Theory are integrated into the e-module design through the organization of material that takes into account the cognitive structure of learners, from simple to complex concepts.

The Problem-Based Learning (PBL) approach is also integrated into the e-module through the presentation of contextual case studies and real-world problem scenarios that require learners to apply the knowledge they have acquired to analyze, evaluate, and formulate solutions in facing 21st-century challenges (Wiyono et al., 2024). For example, alternating current electricity problems were introduced progressively from basic concepts (Ohm's law in AC circuits) to more complex applications (resonance in RLC circuits) in order to align with cognitive load principles. The Problem-Based Learning (PBL) approach is explicitly reflected in case studies related to Palembang LRT, where students are asked to analyze electrical efficiency, power distribution, and safety mechanisms, thereby directly linking theoretical understanding with observed improvements in creative thinking indicators.

The results of the effectiveness test at the dissemination stage show that the STEM-based e-module in the context of Palembang LRT significantly improved students' creative thinking skills. This is indicated by an overall N-Gain score of 0.75, which is classified as "high." Further analysis of the four creative thinking indicators reveals interesting variations in improvement. The elaboration indicator achieved the highest score (N-Gain = 0.82), followed by originality (0.78) and flexibility (0.76). Meanwhile, the fluency indicator recorded the lowest increase, although it was still in the high category with an N-Gain of 0.71.

The high increase in the elaboration indicator can be attributed to the task design in the e-module, which specifically requires students to develop detailed and in-depth explanations. For example, in the activity analyzing the energy efficiency of the LRT's regenerative braking system, students were not only asked to conclude "high efficiency," but also had to describe the energy conversion process, calculate the quantities involved, and relate them to the principles of electromagnetic induction. The real and complex context of the LRT provided many dimensions for students to elaborate their answers with in-depth physical arguments.

Conversely, the numerically lower fluency indicates that although the e-module is effective in promoting the quality of answers, challenges remain in stimulating the quantity of ideas generated spontaneously. This is strongly suspected to be due to the abstract nature of some core concepts of alternating current electricity, such as impedance and phase difference. These concepts limit students' initial "idea bank," so even though the tasks are designed to be open-ended, students need more time to generate multiple alternative solutions. Observations during the trial showed that on average, students only provided 2-3 different ideas within the given time for problems related to these abstract concepts, compared to 4-5 ideas for more concrete problems.

Based on the stages that have been carried out, the results indicate that the STEM-based AC electricity e-module in the context of the Palembang LRT for training high school students' creative thinking skills is valid, practical, and effective. However, this study has several limitations. The implementation was only conducted in one school with a limited number of students, so the generalizability of the findings is restricted. In addition, the assessment of creative thinking relied on written essay responses, which may not fully capture students' creativity in practical or collaborative settings. Future research should therefore involve larger and more diverse samples and integrate multiple forms of assessment such as performance-based tasks and classroom observations. This finding aligns with previous research that produced a similar product, namely a physics e-module based on local wisdom to enhance creative thinking skills, which was found to be valid and practical (Al, 2025; Wiyono et al., 2024), a STEM physics module integrated with local wisdom "Beduk" to enhance middle school students' creative thinking skills, which is valid and practical (Almuharomah et al., 2019; Yusuf, 2023), an augmented reality-assisted physics e-module based on local wisdom "Becak" to enhance mathematical communication, develop teaching materials on momentum and impulse, which is valid, practical, and effective, and enhance critical thinking skills effectively (Anikarnisia, 2020) an electronic module on optical instruments based on STEM using the Flip PDF Professional application that is valid and practical (Rizaldi et al., 2022).

In terms of contextual integration, the Palembang LRT was concretely embedded into the e-module through examples and problem scenarios. For instance, the concept of alternating current electricity was linked to the operation of LRT electric motors, the role of transformers in regulating voltage for train systems, and the use of RLC circuits in signal and safety devices. One activity required students to calculate the efficiency of energy transfer in the LRT system, while another explored how resonance conditions in AC circuits could affect the stability of power distribution. These specific connections made abstract physics concepts more meaningful and relevant to students' everyday environment. The Palembang LRT operation comprehensively integrates various physics principles. Its propulsion system applies magnetic fields through traction motors based on Lorentz's Law, while electromagnetic induction in regenerative braking saves up to 35% of energy by converting kinetic energy into electricity. Thermodynamic aspects are realized in the motor and cabin cooling system that maintains an optimal temperature of 22-24°C. The concept of linear

expansion is accommodated through expansion joints on the 23.4 km long steel rail to compensate for an expansion of 2.2 cm per 100 meters. The principle of Snell's Law is utilized in the fiber optic communication system between stations. The integration of these five physics concepts makes the Palembang LRT a real example of the application of science in modern, efficient and sustainable transportation.

The context of the Palembang LRT is highly relevant to students' lives. Integrating LRT wisdom and the STEM approach into learning is an effective method for fostering students' creativity. Research supports this integration because it combines traditional knowledge with modern scientific principles, creating a culturally relevant learning environment and fostering creative and critical thinking skills (Pujiastuti et al., 2020; Safitri et al., 2024; Septia et al., 2025; Waluyo & Wahyuni, 2021). Many factors can influence students' creative thinking abilities, such as observing or directly experiencing events occurring in their surroundings.

Conclusion

Based on the research conducted, it can be concluded that the STEM-based alternating current electrical e-module in the context of the Palembang LRT has been successfully developed and is considered highly valid in terms of content with a percentage of 83% (very valid), language with a percentage of 73% (valid), and media design with a percentage of 87% (very valid). The e-module developed also falls into the highly practical category in terms of ease of use (96%), appearance and design (93%), presentation of material (94%), and benefits (94%). These findings highlight that the integration of STEM and local context (Palembang LRT) not only enhances content validity and practicality but also demonstrates the potential of context-based digital learning resources to support students' creative thinking skills and provide meaningful learning experiences in physics. This study implies that the developed e-module can serve as an innovative and effective learning resource for both teachers and students, particularly in promoting 21st-century competencies such as creative thinking. Nevertheless, this research is limited by its relatively small sample size and the dependence on online access, which may reduce accessibility for schools with weak internet infrastructure. Therefore, future research should focus on expanding the implementation of STEM-based e-modules to different physics topics and diverse contexts, while also addressing technical limitations, so as to maximize their impact on science education.

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Conceptualization, D.P.S. and K.W.; methodology, D.P.S.; software, D.P.S.; validation, D.P.S., K.W. and S.M.S.; formal analysis, D.P.S.; investigation, D.P.S.; resources, D.P.S.; data curation, D.P.S.; writing original draft preparation, D.P.S.; writing review and editing, D.P.S., K.W. and S.M.S.; visualization, D.P.S.; supervision, K.W. and S.M.S.; project administration, D.P.S.; funding acquisition, K.W.

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Conflicts of Interest

During the research process and preparation of this research report, there was no personal conflict of interest that influenced the research results, either in data collection, data presentation, or interpretation of research data. Each author has agreed to publish the results of this research at his/her own expense so that no one can interfere with the process of publishing this research.

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