



Promoting Critical Thinking through an SDG-Integrated STEAM E-Module for Grade X High School Students

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Abstract: This research aims to produce STEAM-based E-Modules that are valid, practical, and effective in improving students' critical thinking skills in mathematics subjects. This research uses the ADDIE development model with five steps: Analysis, Design, Development, Implementation, and Evaluation. The validity of the E-Module was tested by four validators, namely experts in instruments, media, materials, and languages. Trial I involved 3 students, while trial II was carried out on 2 educators and 25 students. The results showed that the STEAM-based E-Module on linear program materials had excellent validity, with a score of 83% for product experts, 93% for subject matter experts, and 93% for linguists. The practicality of this E-Module is very high, with the trial of students obtaining a score of 98% and educators 96%, both of which are in the category of "Very Practical". The effectiveness of this E-Module can be seen from the increase in student learning outcomes, namely from a pretest score of 49.60 to a posttest score of 81.40, with an N-gain of 0.62 which is included in the "Medium" category. In addition, students' critical thinking abilities earned an average score of 3.03 out of 4, which indicates the "Pretty Good" category. The results of this study show that STEAM-based E-Modules are effective in improving students' critical thinking skills and are practically used in mathematics learning.

Keywords: ADDIE; Critical Thinking; Development; E-Module

Introduction

Education is one of the main pillars in advancing all aspects of the life of the nation and state. As a driving force, education shapes the individual as a whole, encompassing physical, spiritual, social, and moral aspects. The education process takes place gradually, planned, and continuously (Tistawati, 2022). Ki Hajar Dewantara emphasized that education aims to develop all children's potential, both character, intellectual, and physical, so that they can live in harmony with their environment and contribute positively to society. Education also plays a key role in opening up better life opportunities for individuals.

Education is not only interpreted as an activity, but also includes a structured learning process. Learning functions to optimize the development of students through behavioral change from incapable to capable (Fransiskus & Mifda, 2024). Effective learning not only

transfers knowledge, but also equips students with the ability to apply concepts in various situations (Dewi et al., 2024; Mashudi, 2021; Rasyida Syafawani & Prasetyo, 2024). Therefore, learning in the digital era needs to integrate critical thinking skills, creativity, collaboration, communication, and mastery of literacy, numeracy, and technology (Hilmiah & Salehudin, 2024; Mantau & Talango, 2023; Murtopo et al., 2023)

One of the important skills that must be developed in learning is the ability to think critically (Rahmaini & Ogylya Chandra, 2024; Jannah et al., 2022; Rifa Hanifa Mardhiyah et al., 2021). These skills enable students to solve problems analytically, both simple and complex (Fauji et al., 2023; Harijanja & Susiana, 2022). However, weak confidence and difficulty understanding problems with different language variations are often obstacles (Sari & Tarigan, 2024; Wasitoh et al., 2023). In fact, critical thinking plays a big role in preparing students to face real-life challenges. According to Noorhapizah et al.

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(2022); Ridwan (2021), Critical thinking can improve the quality of learning outcomes. Najaah (2021) Facione identifies four indicators of critical thinking: interpretation, analysis, evaluation, and inference. Interpretation refers to the ability to clearly group problems; analysis on proof of concept; inference on the drawing of conclusions; and evaluation of the assessment of the statement objectively (Syafitri et al., 2021). Achieving these four indicators is important to form a mature and structured mindset.

In the context of learning mathematics, critical thinking skills become very relevant. Mathematics is the foundation of modern technological development and has made a great contribution to various disciplines (Aslamiah et al., 2024; Nurhida & Safari, 2024; Zulmaulida & Saputra, 2024). Therefore, students need to be trained to think logically, analytically, and critically from an early age (Haryadi, 2023). However, the 2018 PISA results show that Indonesian students' math scores are still below the international average (Habibi & Suparman, 2020), so that more innovative learning strategies are needed.

Linear Program materials in high school have great potential to train critical thinking skills because they discuss the optimization of goal functions (Mahendra et al., 2023; Rasyida Syafawani & Prasetyo, 2024). The results of the analysis of critical thinking skills of grade X students showed an overall average score of 61% with a low category. The highest indicators were in interpretation (81%), while analysis, evaluation, and inference were in the medium to low category. This condition indicates the need to develop learning strategies that are able to improve critical thinking skills as a whole.

The STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach is considered to be a solution. Research shows that STEAM-based learning improves students' critical thinking, creativity, and collaboration skills compared to conventional methods (Arnold et al., 2025; Bosman & Shirey, 2023; Setyarto et al., 2020). In math learning, STEAM motivates students to innovate and find more effective problem-solving strategies (Filipe et al., 2024; López Carrillo et al., 2024; Sayuda et al., 2025; Setyarto et al., 2020; Tang et al., 2025)

The availability of quality teaching materials is the key to the successful implementation of STEAM. One of them is the E-Module which is able to present material in a systematic, interesting, and interactive manner (Mutiarra Sakinah & Dori Lukman Hakim, 2023; Salfia, 2021; Smith et al., 2025). E-Modules equipped with multimedia features such as videos, animations, and interactive exercises can make it easier to understand complex concepts and encourage student learning independence (Andriani & Dwiningsih, 2024; Darpiyah

& Sulastri, 2023; Daud et al., 2024). However, the results of observations at SMAN 3 Bantan show that the available E-Modules are still limited to PDF format with memorized content, so they do not support the development of critical thinking skills.

Based on the needs analysis, the majority of students (92%) stated that they need an E-Module that can be used independently to learn complex mathematics materials, especially Linear Programs. In addition, teachers at SMAN 3 Bantan have not implemented the STEAM approach because there is no STEAM-based E-Module available for the material. Therefore, this study developed a STEAM-based E-Module on the Linear Program material as an effort to improve the critical thinking skills of high school students, while supporting active, creative, and innovative learning according to the demands of the 21st century.

Method

This research uses the Research and Development (R&D) method with the ADDIE model (Analyze, Design, Develop, Implement, Evaluate) (He, 2024; Huang, 2024; Wang, 2024) to develop and test the effectiveness of STEAM-based E-Modules on the material of the Mathematics Linear Program for class X of high school. The analysis stage includes the needs, curriculum, and characteristics of the students. Product design includes design of displays, materials, media, and evaluation instruments using Canva and Flip PDF Professional. The development stage realizes the design into a product, is validated by experts, and then revised. Implementation was carried out in the classroom with a STEAM approach, followed by practicality and effectiveness tests. The evaluation includes an analysis of user perceptions and learning outcomes.

The research subjects consisted of media, material, language experts, two mathematics teachers, and students of class X of SMAN 3 Bantan, with the object of research in the form of an E-Module of a STEAM-based Linear Program. Data was collected through observation, interviews, questionnaires, tests, and documentation. The analysis was carried out descriptively, quantitatively, and qualitatively using the Likert scale, normalized gain (N-gain), and assessment of critical thinking skills based on five main indicators.

Result and Discussion

The STEAM-based E-Module development process in the Mathematics class X of high school is carried out through five main stages of the ADDIE model, namely analysis, design, development, implementation, and

evaluation. Each stage is carried out systematically so that the resulting product is relevant to learning needs and has a high level of validity, practicality, and effectiveness

Stages of Analysis

At the analysis stage, data on the needs of students was collected through questionnaires and interviews. The results of the needs analysis showed that as many as 92% of students needed E-Modules as a means of independent learning, while 80% stated that the previously available E-Modules did not fully help to understand complex mathematical concepts. In addition, 98% of students want an E-Module that can improve critical thinking skills. The analysis also found that 96% of students have personal mobile devices, so the utilization of technology-based learning is very feasible to be implemented. The curriculum analysis is carried out by referring to the Independent Curriculum, choosing linear program materials as the focus of learning. Meanwhile, the analysis of students' characteristics shows that they need challenge-based learning that integrates STEAM aspects to facilitate the strengthening of critical thinking skills.

Stage of Design

The design stage begins with the preparation of an E-Module design that combines text, image, audio, and learning video content. Canva's software is used for graphic design creation, while Flip PDF Professional is used to convert materials into interactive flipbook formats that can be accessed online or offline. These e-Modules are designed not only to deliver material, but also to provide STEAM-based activities that are relevant to the context of everyday life. In addition, formative and summative assessments are prepared through Google Form to facilitate continuous evaluation of student understanding.

Stage of Development

At the development stage, the initial design of the E-Module was realized into a test-ready product. This product was then validated by four experts, namely experts in instruments, media, materials, and languages. The validation results showed that all aspects were in the "Very Valid" category, with a percentage of media validity of 86%, material 93%, language 93%, and instruments of 100%. The revision process is carried out based on validator input, which includes improving the page layout, adding supporting video sources, improving usage instructions, and revising exercise questions to be more varied and contextual.

Stage of Implementation

The implementation stage was carried out through two trials. The first trial involved three students to assess

initial practicality, with an average practicality of 98% which was categorized as very practical. The second trial involved two educators and 25 students. At this stage, practicality according to educators reached 96% and 91%, while practicality according to students had an average of 98%, all of which were classified as very practical. The effectiveness of the E-Module was tested through a comparison of pretest and posttest scores. The results showed a significant increase, with an average pretest score of 50.20 and a posttest of 81.20. The N-gain value obtained was 0.61, which belongs to the medium category. In addition, the critical thinking ability questionnaire showed an average score of 3.03 on a scale of 4, with the explanatory indicator obtaining the highest score of 3.24 and the lowest inference indicator of 2.72.

Stage of Evaluation

The last stage, namely evaluation, is carried out by reviewing all aspects of the product based on the input of validators, teachers, and students. The final revision ensures that the E-Module can be used optimally, has an attractive appearance, relevant content, and is easily accessible. In general, the perception of teachers and students is very positive. They consider this E-Module to be not only interactive and easy to use, but also helps with the understanding of mathematics material and motivates students to be more active in learning. Quantitative and qualitative data obtained at this stage confirm that the STEAM-based E-Module developed is effective in improving mathematics learning outcomes while developing students' critical thinking skills.

Conclusion

This study concludes that the STEAM-based E-Module to improve students' critical thinking skills in high school grade X Mathematics subjects has been successfully developed through the stages of analysis, design, development, implementation, and evaluation, with validation results from instrument, media, material, and language experts who are all categorized as "Very Valid". The practicality test showed a very high level of practicality from both students and educators (91-98%). The effectiveness of learning is evident from the increase in students' average scores from 49.60 to 81.40 with an N-gain of 0.62 (the "Medium" category) and critical thinking skills in the "Quite Good" category. Thus, STEAM-based E-Modules are declared valid, practical, and effective for use in mathematics learning, especially in linear program materials.

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Author Contributions

Conceptualization, P. and R.; methodology, P. and R.; software, P.; Validation, M., R., A. and A.; formal analysis, P.; Research, P.; resources, P.; data curation, P.; writing – preparation of original drafts, P.; writing – review and editing, P., R., A and U.; Visualization, P.; All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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