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Development of a STEM-Based Circular Motion Module Integrated with the Engineering Design Process

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Abstract

The low mathematics literacy and science skills of Indonesian students can be caused by among other, the lack of learning media that can improve students' conceptual understanding, especially in physics. The STEM approach and the Engineering Design Process (EDP) methods can improve problem-solving and creative thinking skills. Therefore, this study aims to develop learning media with ~~the~~ STEM approach and ~~the~~ Engineering Design Process method for Physics subject, namely Circular Motion. The method used in this study is Research and Development with the ADDIE development model, which is limited to: 1) Analysis, 2) Design, 3) Development. The design and development stage involved material and learning experts to test the feasibility of the developed module. The average value of material feasibility of the module is 85.00% with the category "feasible and can be used with minor revisions." While the average value of learning feasibility is 87.00% with the category "very feasible and can be used without revision". The result of this study is expected to be the basis for the development of other learning media based on STEM and EDP syntax to improve students' skills.

Keywords: circular motion, engineering design proess, module, STEM

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INTRODUCTION

In the 2022 Programme for International Student Assessment (PISA), Indonesia was ranked 54th out of 77 participating countries. Indonesian students scored below the OECD (Organisation for Economic Co-Operation and Development) average scores in mathematics, literacy, and science. Specifically, only 34% of Indonesian students reached Level 2 or higher in science. There are almost no students demonstrating high-level scientific skills (OECD & PISA, 2023). This indicates the ability to explain scientific phenomena and apply their knowledge to identify issues is low.

This low performance may be attributed to instructional practices that remain predominantly teacher-centered, where the teacher serves as the primary source of information, and learning is delivered through lectures (Ho & Gan, 2023; Rozhenkova et al., 2023). In physics education, students are often exposed to mathematical problem-solving without being encouraged to connect physics concepts to real-world contexts or everyday phenomena (Tong et al., 2024). As a result, students frequently struggle to grasp the relevance of physics in daily life, which contributes to a lack of interest and engagement in the subject. Brakhage et al. (2023) further noted that many physics learning materials fail to capture students' attention, making the learning process less meaningful and effective.

Moreover, Carrete-Marín et al. (2024) found that many teachers still rely heavily on conventional teaching materials such as textbooks and printed worksheets. Interviews and questionnaires conducted with teachers revealed a growing demand for more dynamic and interactive digital learning resources, particularly physics modules. Research has shown that interactive physics modules offer multiple pedagogical benefits. They not only enhance scientific literacy (Hwang et al., 2022; Fang & Guo, 2022), but also promote independent learning by cultivating attributes such as confidence, motivation, initiative, discipline, and responsibility (Banda & Nzabahimana, 2022).

One of the most challenging topics for students in physics is circular motion. Students often find difficulties to understand the core concepts such as force vectors and their application within rotating systems. Bouchée et al. (2021) emphasized that many of these difficulties arise from the abstract nature of centripetal and centrifugal forces, which students find hard to visualize and contextualize without appropriate instructional supports. This underscores the importance of developing effective teaching strategies and resources tailored to such complex topics.

To address these challenges, there is a pressing need to shift toward student-centered, contextual learning approaches—such as the STEM (Science, Technology, Engineering, and Mathematics) framework (Fan et al., 2020; Morel, 2021; Siller et al., 2024). Through the STEM approach, students are not only expected to master scientific concepts but also to relate them to real-world situations, thereby fostering higher-order thinking skills including problem-solving and creativity (Chang et al., 2021). A research has shown that STEM-based learning can significantly increase students' engagement, understanding, and analytical capabilities (De Loof et al., 2021).

The STEM approach is closely aligned with the Engineering Design Process (EDP), a methodical strategy that guides learners through the stages of problem identification, ideation, planning, creation, and refinement. Both STEM and EDP aim to empower students with essential 21st-century skills (Priemer et al., 2020; Galanti & Holincheck, 2024). Several studies have demonstrated that learning modules incorporating EDP are effective in nurturing creative thinking and practical problem-solving (Chen & Chan, 2021). Furthermore, STEM-integrated materials help students in developing solutions to everyday problems, making learning more relevant and applicable (Syahiddah et al., 2021).

Given this context, there is a strong rationale for developing STEM-based physics modules that integrate the Engineering Design Process. Such materials are not only pedagogically sound but also crucial in addressing existing gaps in science education. In response, this study focuses on the development of a circular motion learning module that adopts the STEM approach and follows the syntax of the Engineering Design Process.

METHOD

This study employed a Research and Development (R&D) approach using the ADDIE model as the framework for instructional design. The ADDIE model consists of five sequential phases: Analysis, Design, Development, Implementation, and Evaluation. However, this research was limited to the first three stages—Analysis, Design, and Development—focusing on the creation and expert validation of the instructional module.

The data collected in this study comprised both quantitative and qualitative types. Quantitative data were obtained through feasibility assessment questionnaires, while qualitative data were gathered from expert comments and suggestions provided during the validation process. The feasibility evaluation of the module was conducted by subject matter experts in physics, instructional media, and pedagogy.

The instrument for assessing the module's feasibility was adapted and modified from Anisa et al. (2024), which is specifically designed to evaluate instructional materials based on the Engineering Design Process (EDP) syntax. This instrument allows for a structured and comprehensive evaluation of the module in terms of content accuracy, language use, instructional design, and alignment with the STEM-EDP approach. The score is calculated using the following formula.

$$N = \frac{T_{Se}}{T_{Sh}} x\ 100\%$$

With
$N = score$
$T_{Se} = Total\ empiric\ score$
$T_{sh} = Total\ maximum\ score$

Feasibility criteria of the module is shown by Table 1.

Table 1. Feasibility criteria

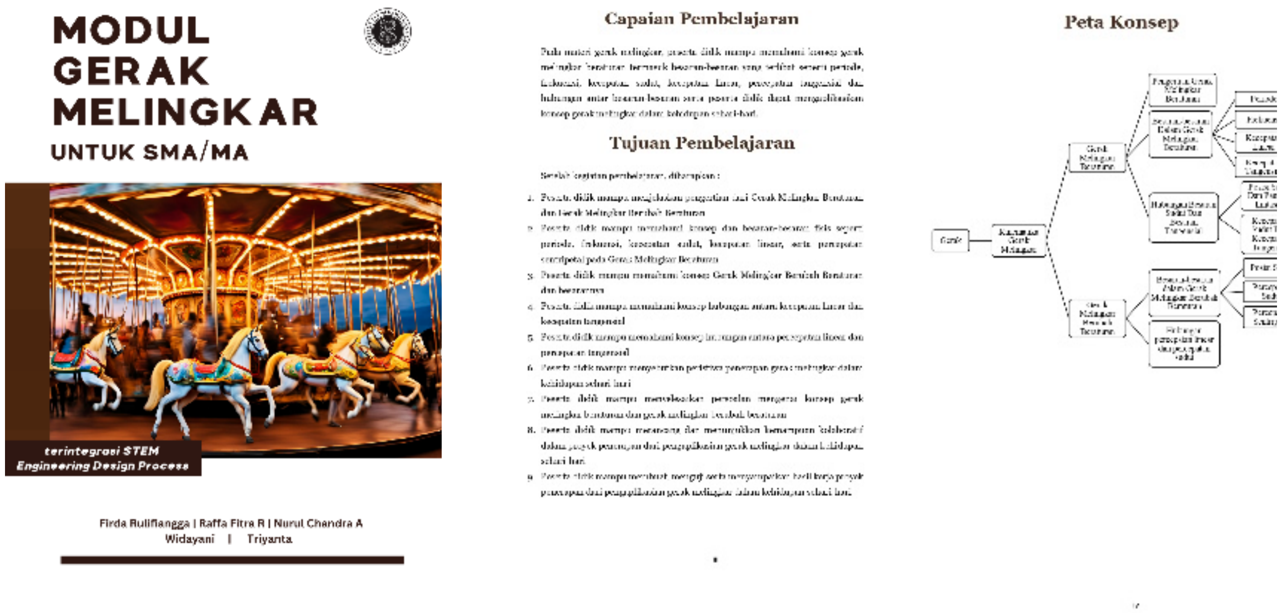
Score Range	Category
85,01 % ≤ N ≤ 100,00 %	Highly feasible
70,01% ≤ N ≤ 85,00%	Feasible with minor revisions
50,01% ≤ N ≤ 70,00%	Less feasible and recommended not to be used
0,00 % ≤ N ≤ 50,00%	Not feasible and cannot be used

RESULTS AND DISCUSSION

This section presents the outcomes of the development and validation of a physics learning module on circular motion based on the STEM approach and the Engineering Design Process (EDP). The development followed the ADDIE model and was limited to the first three phases: Analysis, Design, and Development. The results are explained in four aspects: analysis of needs, module development, feasibility assessment, and implications of the developed module. Both quantitative data, obtained from expert validation using structured questionnaires, and qualitative data, derived from expert feedback, are integrated into the discussion. Each subsection is supported with findings and analyzed within the framework of relevant literature and pedagogical principles.

Module Development

The circular motion module developed using the STEM approach and EDP syntax was structured into three major sections: introduction (cover, learning objectives, concept map), main content (materials, sample problems, student projects, practice questions), and closing (glossary). The instructional design was intended to support student-centered learning and real-world problem-solving through projects aligned with the EDP phases: Ask, Imagine, Plan, Create, and Improve.

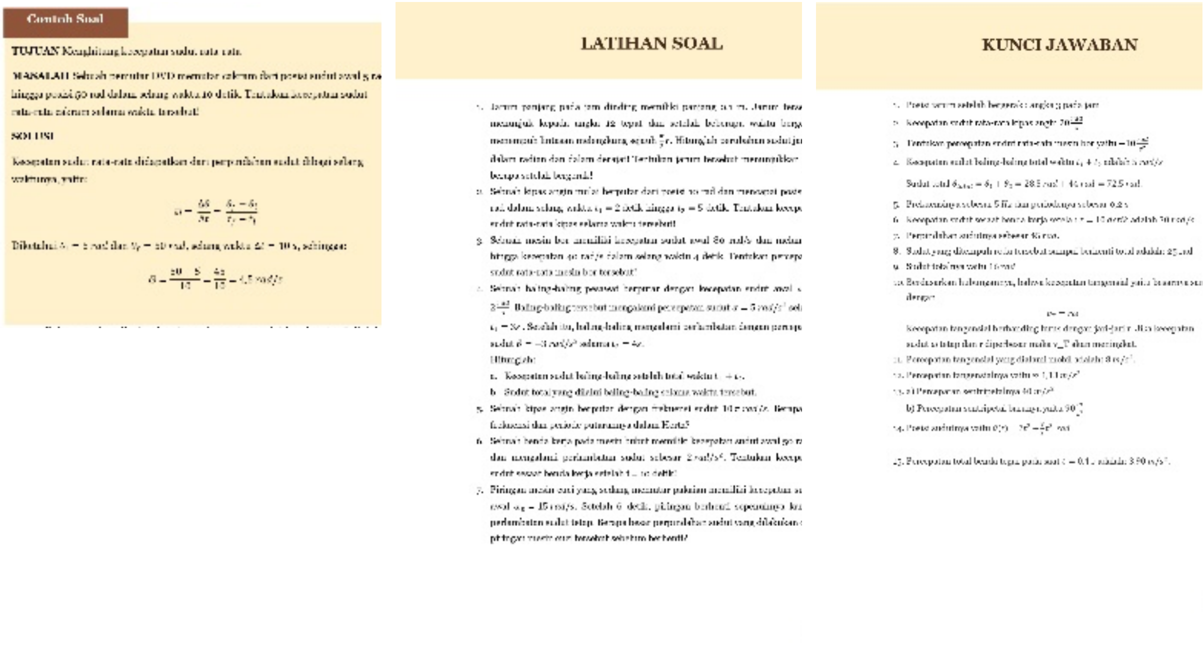


(a) (b) (c)

Figure 1. Module Introduction: (a) Module cover, (b) Learning objectives and outcomes, (c) Concept map

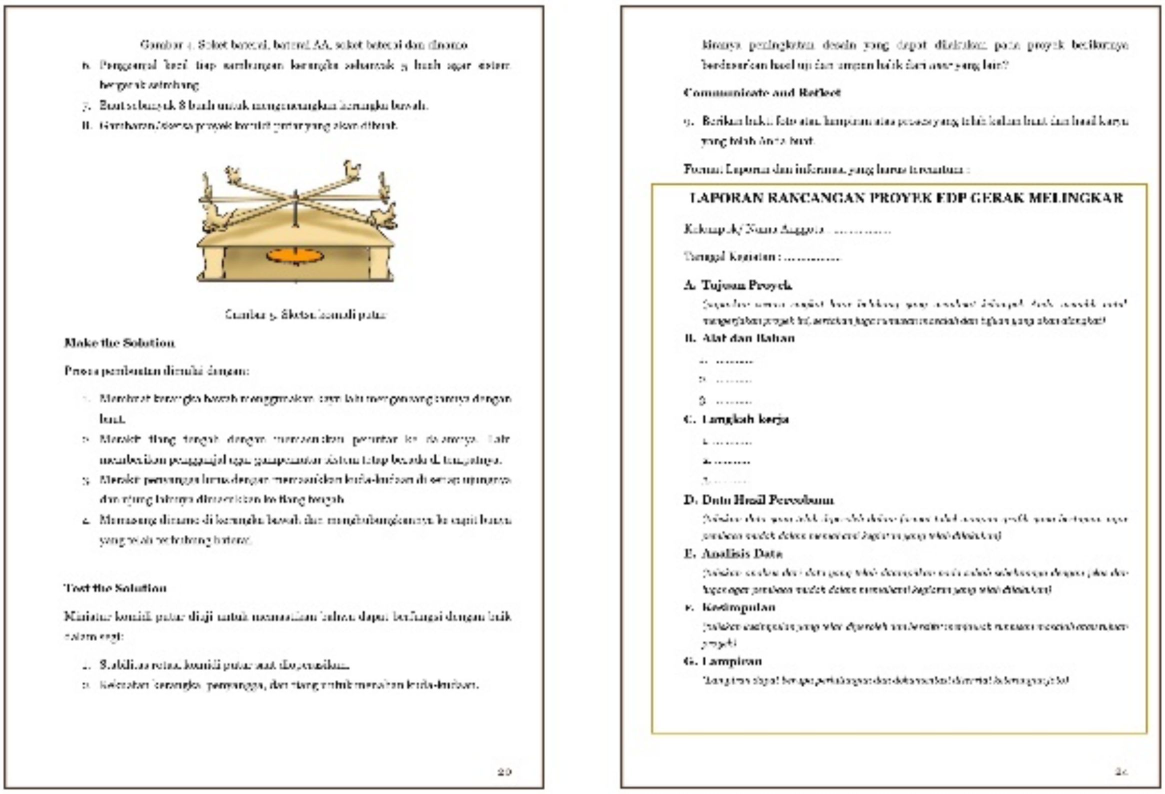
(a) (b) (c)

Figure 2. Module Content: (a) Apperception, (b) Uniform Circular Motion, (c) Non-uniform Circular Motion



(a) (b) (c)

Figure 3. Exercises in the Module: (a) Example problem, (b) Practice questions, (c) Answer key



(a) (b)

Figure 4. EDP-Based Student Activities: (a) Merry-go-round project, (b) Student creativity project

One of the featured activities was a project on creating a rotating system (e.g., a miniature merry-go-round), which helped students visualize and apply the concepts of circular motion in a tangible way. By incorporating both theoretical content and hands-on learning, the module aimed to develop students' understanding while enhancing their creativity, critical thinking, and collaborative skills.

Feasibility Assesment

The developed module was evaluated for its feasibility by two experts: a subject matter expert and an instructional design expert. The results of the feasibility assessment are presented in Table 3.

Table 2. Feasibility Test Reults

No	Aspect	Percentage	Interpretation
Content Feasibility			
1.	Alignment with the curriculum	90%	Highly feasible
2.	Grammar and language use	80%	Feasible with minor revisions
3.	Presentation technique	80%	Feasible with minor revisions
4.	Relevance of questions to content	90%	Highly feasible
Instructional Feasibility			
1.	Use of module in learning	84%	Feasible with minor revisions
2.	STEM and EDP-based instruction	90%	Highly feasible

In addition to quantitative data, this study also gathered qualitative input in the form of suggestions and critiques provided by the experts. These comments focus on the circular motion module developed using the STEM approach and the Engineering Design Process (EDP) syntax, as detailed in Table 3.

Table 3. Suggestions and Feedback from Experts

No	Aspect	Suggestions and Comments from Experts
1	Content Feasibility	1. The examples and problems in the module heavily emphasize math skills. To fully reflect the EDP approach, engineering skills should also be included. 2. Project activities align well with STEM and EDP elements. 3. Test items should also assess STEM and EDP thinking. 4. Ensure consistency in terminology ('project' vs. 'projek').
2	Instructional Feasibility	1. Revise learning objectives for clarity. 2. If student outputs are guided by specific criteria, clearly define constraints as part of the evaluation.

Implications of the Developed Module

The results of this study demonstrate the potential of STEM-EDP–based learning modules to enrich the teaching and learning of physics, particularly for abstract topics such as circular motion. By integrating conceptual knowledge with practical application, the module supports the development of 21st-century competencies, including critical thinking, creativity, communication, and collaboration. Furthermore, it contributes to the body of instructional resources that emphasize contextual learning.

While the module has been validated by experts and deemed feasible, further studies are recommended to implement and evaluate its effectiveness in classroom settings. Broader testing with diverse student populations and different school contexts would provide empirical evidence on its impact on learning outcomes and student engagement. Additionally, the module could be adapted to other physics topics to extend its pedagogical utility.

Limitations of the Study

This study presents several limitations that should be considered when interpreting the findings and their implications. First, the module development process was conducted only up to the Development stage of the ADDIE model. As such, the study did not include the Implementation and Evaluation phases, meaning that the module's effectiveness in improving students' learning outcomes and skills has not been empirically tested in actual classroom settings.

Second, the module's feasibility was assessed by two experts focusing on content and instructional design. Although the results indicated a high level of feasibility, the evaluation did not involve teachers as direct users or students as end-users. Including these stakeholders could have provided more comprehensive insights into the module's usability and appeal in real educational contexts.

Third, the module still exhibited a strong emphasis on mathematical skills, with limited integration of explicit engineering skills in the exercises and activities. This may affect the extent to which the Engineering Design Process (EDP) is fully internalized by students during the learning process.

Fourth, the study was limited to the topic of circular motion at the senior high school level and has not been tested on other physics topics or educational levels. Therefore, the generalizability of the findings remains limited and requires further research to examine its applicability across different subject areas and learning environments.

CONCLUSION

This study addressed the need for more effective physics learning by developing a STEM-based circular motion module integrated with the Engineering Design Process (EDP). In this study, a circular motion module has been developed using the STEM approach and EDP syntax. The module was found to be highly feasible, with expert evaluations indicating strong alignment with curriculum standards and effective instructional design.

The integration of STEM and EDP provided a contextual and student-centered learning approach that supports both conceptual understanding and creative problem-solving. While the study did not include classroom implementation, the developed module offers a promising instructional resource. Future research should focus on testing its effectiveness in classroom settings and expanding its use to other physics topics.

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