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PAPER

Designing and Evaluating an Android-Accessible Problem-Based Learning E-Module for Rotational Dynamics: Evidence from Validity, Practicality, and Initial Learning Effectiveness

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ABSTRACT

This study developed and evaluated an Android-accessible Problem-Based Learning (PBL) e-module for rotational dynamics and rigid-body equilibrium. The mobile-readable module addressed students' difficulties in visualizing physical systems, interpreting problems, and applying rotational concepts through structured reasoning. A development-and-evaluation design adapted from the 4D framework was used, limited to the Define, Design, and Develop stages. Participants comprised six physics lecturers, two physics teachers, and 33 Grade 12 students at SMA Negeri 2 Padang. Data were collected using an expert-validation sheet, teacher and student practicality questionnaires, and a 30-item achievement test administered as a pre-test and post-test. Analyses included Aiken's V, practicality percentages, descriptive statistics, the Shapiro–Wilk test, a paired-samples t-test, effect-size estimation, and normalized gain. The e-module achieved an Aiken's V of 0.89. Teacher practicality reached 96.5%, classified as very practical, while student practicality reached 85.05%, classified as practical. Students' mean achievement score increased from 53.39 to 77.24, with a significant mean difference of 23.85 points, t (32) = 30.44, $p < 0.001$, and an exceptionally large within-participant effect, *Cohen's* $d_z = 5.30$. The mean N-gain was 0.52, indicating moderate improvement. These findings provide initial evidence that the e-module is valid, practical, and supports learning improvement, although the one-group design does not establish causality.

KEYWORDS

problem-based learning (PBL), e-module, physics learning, rotational dynamics, rigid-body equilibrium, mobile-accessible learning

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1 INTRODUCTION

Education in the 21st century increasingly emphasizes critical thinking, collaboration, creativity, and the meaningful use of technology in learning. In secondary education, technology-enhanced materials, such as e-modules, are often promoted as flexible and interactive resources that can support structured learning both in and out of the classroom [1], [2]. Nevertheless, the educational value of digital materials depends less on technology itself and more on how they are embedded in classroom routines, supported by teacher scaffolding, and experienced through students' participation [3]–[5]. These conditions are particularly important in contexts where device access and digital familiarity vary across learners.

Problem-based learning (PBL) has gained attention as a constructivist approach that engages students in tackling authentic problems and developing reasoning and problem-solving skills [6]–[8]. However, PBL is also associated with recurring implementation challenges in real classrooms. A few active students may dominate group work, time constraints can reduce reflection, and learners often struggle to translate abstract concepts into representations they can reason with [9], [10]. These challenges are especially pronounced in topics such as rotational dynamics and rigid-body equilibrium, which require multi-step reasoning, mathematical representation, and visualization of physical systems [11].

This implementation gap was also observed at SMA Negeri 2 Padang. Classroom observations and teacher–student consultations indicated that, although teachers reported attempts to apply student-centered strategies, learning materials remained largely print-based, and students experienced difficulty visualizing and interpreting rotational-dynamics problems [12], [13]. School assessment data for rotational dynamics in Classes XI F, XI F2, and XI F3 showed average scores of 64, 53, and 51, respectively. These scores were below the school's Minimum Mastery Criterion (*Kriteria Ketuntasan Minimal*, KKM). These patterns suggest that the issue is not only conceptual difficulty but also a resource and implementation gap: students need learning supports that scaffold problem interpretation and visualization, while teachers need instructional media that can be used reliably within classroom constraints.

More specifically, students reported persistent difficulties visualizing physical situations, interpreting problem statements, and connecting related concepts during problem-solving. These difficulties are compounded by limited access to interactive instructional resources that can support conceptual visualization and step-by-step reasoning. Consequently, many students remain reliant on rote procedures and struggle to apply physics ideas meaningfully in problem-based tasks.

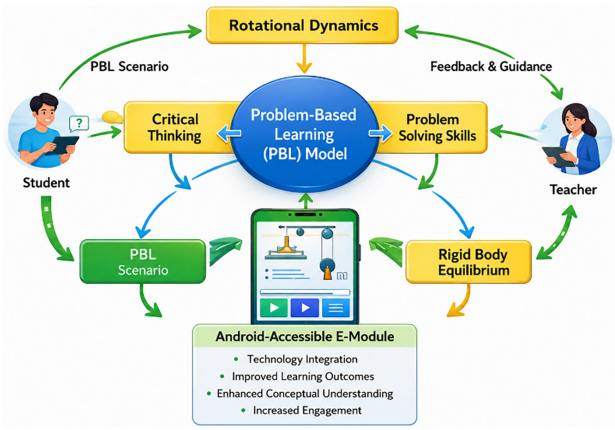


Fig. 1. Conceptual framework for integrating PBL-based e-modules

Figure 1 illustrates the intended interaction flow of the PBL model supported by an Android-accessible e-module for rotational dynamics and rigid-body equilibrium. Students engage with problem scenarios and guided activities within the e-module to support problem interpretation, conceptual visualization, and structured reasoning. Teachers facilitate the process by providing guidance, feedback, and scaffolding at key stages of the PBL cycle, helping students stay on task and reflect on their solutions. In this framework, technology serves as an enabler of access and interactivity (e.g., visuals and QR-linked resources), while learning progress depends on how effectively the e-module is integrated into classroom routines and group-work dynamics.

To address these needs, this study developed an Android-accessible PBL-based e-module that integrates visual materials, QR-linked videos, guided problem scenarios, student activity sheets, browser-based simulations, and reflection activities. The product was developed in Canva and distributed as a mobile-readable digital module rather than as a native Android application. Technology therefore functioned as a means of providing access to structured content and external multimedia resources, while the learning process remained dependent on teacher facilitation and classroom interaction.

This study contributes beyond the production and local evaluation of an instructional material by presenting a transferable design-and-evaluation model for mobile-accessible, PBL-based learning resources. The model integrates contextual problems, visual explanations, QR-linked multimedia, browser-based simulations, guided worksheets, teacher scaffolding, and reflection activities to support the interpretation of mathematically and visually demanding systems. These principles are relevant to online and mobile engineering education and may also inform introductory biomedical engineering and biomechanics instruction, where students reason about torque, equilibrium, lever systems, joint mechanics, and rotational motion. Empirically, the study provides evidence of expert validity, classroom practicality, and initial learning improvement. However, its transferability to university engineering and biomedical engineering contexts requires direct evaluation in those settings. Accordingly, this study addresses the following research questions:

RQ1. What is the validity level of the PBL-based e-module for physics instruction?
RQ2. How practical is the implementation of the PBL-based e-module from teachers' and students' perspectives?
RQ3. How did students' achievement in rotational dynamics and rigid-body equilibrium change from pre-test to post-test?

By answering these research questions, the study supports the development of technology-enhanced, student-centered physics learning materials aligned with the United Nations Sustainable Development Goal 4 (SDG 4: Quality Education), particularly the effort to expand access to quality learning resources and promote meaningful student participation in science education.

2 METHODS

2.1 Study design and participants

This study employed a development-and-evaluation design adapted from the 4D instructional design framework proposed by [14]. The original model comprises four stages: Define, Design, Develop, and Disseminate. The present study implemented only

the first three stages because it aimed to obtain initial evidence of product validity, classroom practicality, and learning effectiveness before wider dissemination.

Participants comprised six physics lecturers from Universitas Negeri Padang as expert validators, two physics teachers from Senior High School (SMA Negeri 2 Padang) as practicality assessors, and 33 Grade 12 students who participated in the practicality and effectiveness assessments. The study was granted an ethical exemption by the Research Ethics Committee of Universitas Negeri Padang, Indonesia (Approval No. 92/KEPK-UNP/10/2025), in accordance with the WHO ethical standards (2011) and the CIOMS Guidelines (2016). Administrative permission was obtained from SMA Negeri 2 Padang. Written informed consent was provided by the students' parents or legal guardians, student assent was obtained, and the participating teachers and validators also provided consent. Participation was voluntary, had no effect on academic grades, and all data were coded and anonymized.

The effectiveness assessment used a one-group pre-test–post-test design. Students completed the pre-test before using the e-module and the post-test after completing the PBL-based learning activities. Because no control group was included, the findings were interpreted as initial evidence of within-group learning improvement rather than definitive evidence of a causal effect. Figure 2 presents the development workflow, in which the term "3D model" refers to the Define, Design, and Develop stages of the 4D framework.

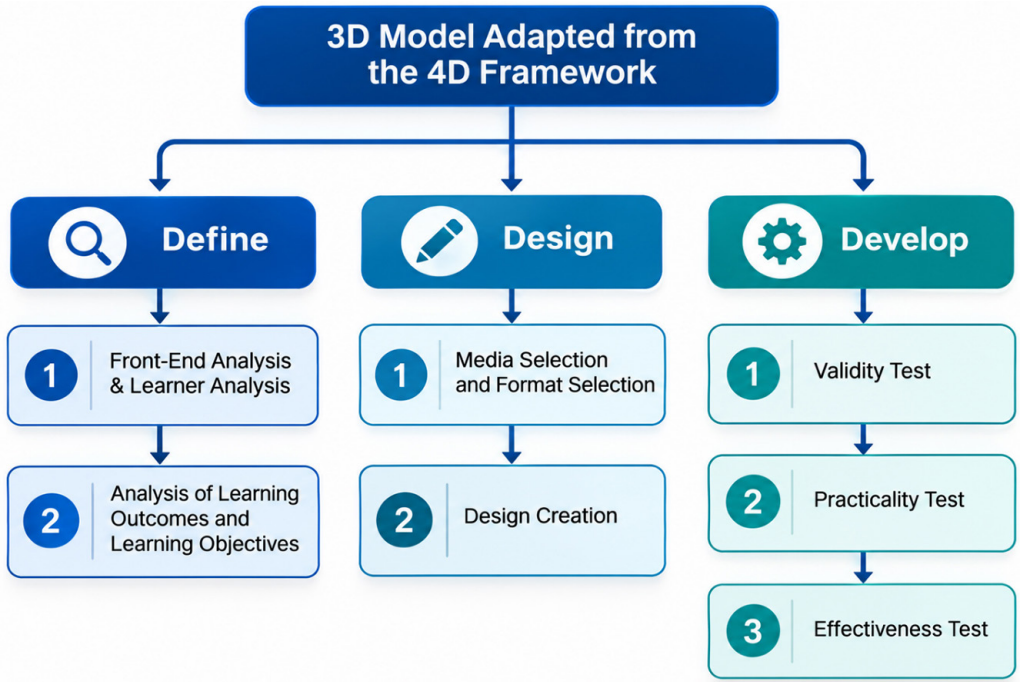


Fig. 2. Three-stage development model of the e-module, adapted from the 4D instructional design framework

2.2 Development procedure

The development procedure consisted of three main stages. Each stage was designed to ensure that the e-module was aligned with curriculum needs, student characteristics, PBL principles, and classroom implementation requirements.

The Define stage aimed to identify learning problems and determine instructional needs. This stage included front-end analysis, learner analysis, curriculum analysis, and analysis of learning outcomes and learning objectives. The analysis focused on the suitability of students' learning needs, curriculum demands, and the characteristics of rotational dynamics and rigid-body equilibrium. The results of this stage served as the basis for determining the content scope, learning objectives, problem contexts, and learning activities for the e-module.

The Design stage focused on preparing the initial prototype of the PBL-based e-module. This stage included media selection, format selection, preparation of learning activities, organization of physics content, development of problem scenarios, and preparation of assessment items. The e-module was designed to integrate the PBL syntax, including problem orientation, problem investigation, group discussion, solution presentation, and reflection. The design also considered readability, visual consistency, navigation, accessibility, and suitability for Grade 12 physics learning.

The Develop stage consisted of expert validation, product revision, practicality testing, and effectiveness testing. Expert validation was conducted to assess the quality of the e-module across content, learning design, graphics, software usability, and PBL integration. The product revision was conducted based on validation score results and item-level assessment indicators. After revision, the e-module was implemented in the classroom to examine its practicality from teacher and student perspectives. The final part of the Develop stage was the effectiveness test, which examined students' learning improvement through pre-test and post-test scores.

2.3 Data collection

Data were collected through validation sheets, practicality questionnaires, and achievement tests. The data used in this study were quantitative. Quantitative data were obtained from expert validation scores, teacher practicality scores, student practicality scores, and students' pre-test and post-test scores.

The primary data consisted of all numerical data collected directly from validators, teachers, and students during the development and evaluation process [15]–[17]. These data included validation, practicality, and learning achievement scores. Secondary data were obtained from curriculum and learning outcome documents, relevant physics learning references, and previous studies on e-module development, PBL implementation, and digital learning media. Secondary data were mainly used to support the Define and Design stages [18]–[20].

The effectiveness data were collected from 33 students using a pre-test and post-test procedure. The pre-test was administered before students used the e-module. The post-test was administered after students completed the e-module learning activities. Both tests measured students' conceptual understanding and problem-solving ability in rotational dynamics and rigid-body equilibrium.

All quantitative data were tabulated and organized using Microsoft Excel. Excel was used for data entry, score conversion, calculation checking, and preliminary tabulation. Statistical analysis was then conducted using SPSS. SPSS was used to analyze descriptive statistics, normality, a paired-samples t-test, and supporting statistical outputs for the effectiveness test.

2.4 Instruments

Four instruments were used in this study: an expert-validation sheet, a teacher practicality questionnaire, a student practicality questionnaire, and a physics achievement test. The instruments were developed or adapted from previous studies on e-module development, digital learning media, and PBL implementation [15]–[17]. Their content and structure were reviewed to ensure alignment with the learning objectives, PBL stages, e-module characteristics, and rotational-dynamics content.

The expert-validation sheet consisted of 37 items distributed across five dimensions: material quality, learning design, graphics, software usability, and PBL integration. Material quality assessed conceptual accuracy, curriculum alignment, content depth, and clarity of physics explanations. Learning design addressed the alignment among learning objectives, instructional activities, assessment tasks, and PBL syntax. Graphics covered layout, typography, readability, visual clarity, and presentation consistency, while software usability assessed navigation, mobile accessibility, technical ease of use, and media responsiveness. PBL integration evaluated problem orientation, inquiry guidance, collaborative learning support, solution presentation, and reflection activities. Each item was rated using a five-point Likert-type scale. Six physics lecturers evaluated the content validity of the instrument using Aiken's V.

Separate practicality questionnaires were administered to teachers and students. The teacher practicality questionnaire contained 19 items, whereas the student practicality questionnaire contained 18 items. Both instruments assessed four dimensions: benefits, attractiveness, ease of media use, and clarity. The teacher questionnaire focused on instructional usefulness, classroom suitability, time efficiency, implementation feasibility, and support for PBL activities. The student questionnaire examined accessibility, visual attractiveness, clarity of instructions, readability, perceived usefulness, and ease of completing the learning activities. Both questionnaires used a five-point Likert-type scale and were reviewed by six physics lecturers for relevance, clarity, and alignment with the intended classroom use of the e-module.

The initial effectiveness of the e-module was assessed using a 30-item multiple-choice physics achievement test administered as both the pre-test and post-test. The test measured students' conceptual understanding and problem-solving ability in rotational dynamics and rigid-body equilibrium, including torque, moment of inertia, rotational motion, equilibrium conditions, and related problem-solving procedures. The items were developed from the curriculum, learning objectives, and cognitive indicators and were reviewed by physics lecturers before administration. Total raw scores were converted to a scale ranging from 0 to 100. Because the study employed a one-group pre-test–post-test design, the results were interpreted as initial evidence of learning improvement rather than definitive causal evidence of effectiveness. Table 1 summarizes the structure and quality evidence for each instrument.

Table 1. Structure and quality evidence of the research instruments

Instrument	Dimensions or Content	Number of Items	Response or Scoring Format	Development and Validity Evidence
Expert-validation sheet	Material quality, learning design, graphics, software usability, and PBL integration	37	Five-point Likert-type scale	Developed or adapted from [15]–[17]; reviewed by six physics lecturers; content validity evaluated using Aiken's V

(Continued)

Table 1. Structure and quality evidence of the research instruments *(Continued)*

Instrument	Dimensions or Content	Number of Items	Response or Scoring Format	Development and Validity Evidence
Teacher practicality questionnaire	Benefits, attractiveness, ease of media use, and clarity	19	Five-point Likert-type scale	Developed or adapted from [15]–[17]; reviewed by six physics lecturers for relevance, clarity, and classroom suitability
Student practicality questionnaire	Benefits, attractiveness, ease of media use, and clarity	18	Five-point Likert-type scale	Developed or adapted from [15]–[17]; reviewed by six physics lecturers for relevance, clarity, and suitability for student use
Physics achievement test	Torque, moment of inertia, rotational motion, rigid-body equilibrium, and problem-solving procedures	30	Multiple-choice items; total scores converted to a 0–100 scale	Developed from the curriculum, learning objectives, and cognitive indicators; reviewed by physics lecturers before administration

2.5 Data analysis technique

Quantitative data were analyzed according to the purpose of each evaluation stage. Data from validation, practicality, and effectiveness tests were analyzed using Microsoft Excel and SPSS. Microsoft Excel was used to organize raw scores, calculate total scores, convert scores into percentages, and prepare data tables. SPSS was used to conduct descriptive statistics, the Shapiro-Wilk normality test, and the paired sample t-test.

Content validity was analyzed using Aiken's V coefficient [21]. Aiken's V was used to determine the level of agreement among expert validators regarding the quality and relevance of each item in the e-module. The validity criteria are presented in Table 2.

Table 2. Criteria for validity score

Index	Category
$V < 0.79$	Invalid
$V \geq 0.79$	Valid

The practicality score was calculated by dividing the total score by the maximum possible score. The formula used was as follows:

$$\text{Practicality Score} = \frac{\text{Total score obtained}}{\text{Maximum possible score}} \times 100\%$$

Practicality scores were interpreted based on the criteria presented in Table 3.

Table 3. Criteria for practicality test score

No	Percentage	Category
1	86%–100%	Very Practical
2	76%–85%	Practical
3	60%–75%	Practical Enough
4	55%–59%	Less Practical
5	≤ 54%	Not Practical

The effectiveness analysis included descriptive statistics, Shapiro–Wilk normality tests, a paired-samples t-test, effect-size estimation, and normalized gain analysis. Descriptive statistics were used to summarize the mean, standard deviation, minimum, and maximum pre-test and post-test scores. The pre-test and post-test distributions were examined separately as descriptive diagnostics. To assess the normality assumption for the paired-samples t-test, an individual difference score was calculated for each participant by subtracting the pre-test score from the post-test score. The Shapiro–Wilk test was then applied to the distribution of these difference scores. A p-value greater than 0.05 was interpreted as indicating no statistically significant departure from normality. Statistical significance for the paired-samples t-test was set at 0.05.

The normalized gain score was used to determine the level of students' learning improvement after using the e-module. The N-gain score was calculated using the following formula [22]:

$$N - gain = \frac{Post\text{-}test - Pre\text{-}test}{Maximum\,Score - Pre\text{-}test}$$

N-gain was classified into three categories: (1) high ($g \geq 0.70$), (2) medium ($0.30 \leq g < 0.70$), and (3) low ($g < 0.30$).

3 RESULT

3.1 Define

The Define stage identified the main instructional problems in teaching rotational dynamics at SMA Negeri 2 Padang. Classroom observations and teacher-student consultations showed that physics learning still relied heavily on printed materials and teacher explanation. As a result, students had limited access to interactive learning resources. Group-based learning was also not consistently implemented, as a small number of active students often dominated discussion activities. These findings indicate the need for a learning medium that can support guided inquiry, active participation, and structured problem-solving.

The initial learning condition was also reflected in students' assessment data. The average scores for rotational dynamics in classes XI F, XI F2, and XI F3 were 64, 53, and 51, respectively, which were below the Minimum Mastery Criteria (KKM). In addition, 49% of students reported difficulty understanding key rotational dynamics concepts, including torque, moment of inertia, rotational kinetic energy, and angular momentum. These concepts require visual representation, mathematical reasoning, and step-by-step interpretation of problems. Therefore, the results of the Define stage

became the basis for developing a PBL-based e-module that includes visual scaffolds, guided problem scenarios, interactive learning materials, and reflection prompts.

3.2 Design

The e-module was developed in Canva using an A4 digital format and designed for convenient access through Android smartphones and other mobile devices, in accordance with relevant educational media design guidelines [23]. Rather than functioning as a native Android application, the product was distributed as a mobile-readable digital module containing QR codes that directed students to supplementary videos and browser-based simulations. Responses, learning progress, and student submissions were not recorded automatically within the module but were monitored and managed by the teacher during classroom implementation. Figure 3 shows six representative screens from the e-module. The module was organized into opening, content, and closing sections to provide a clear learning sequence.

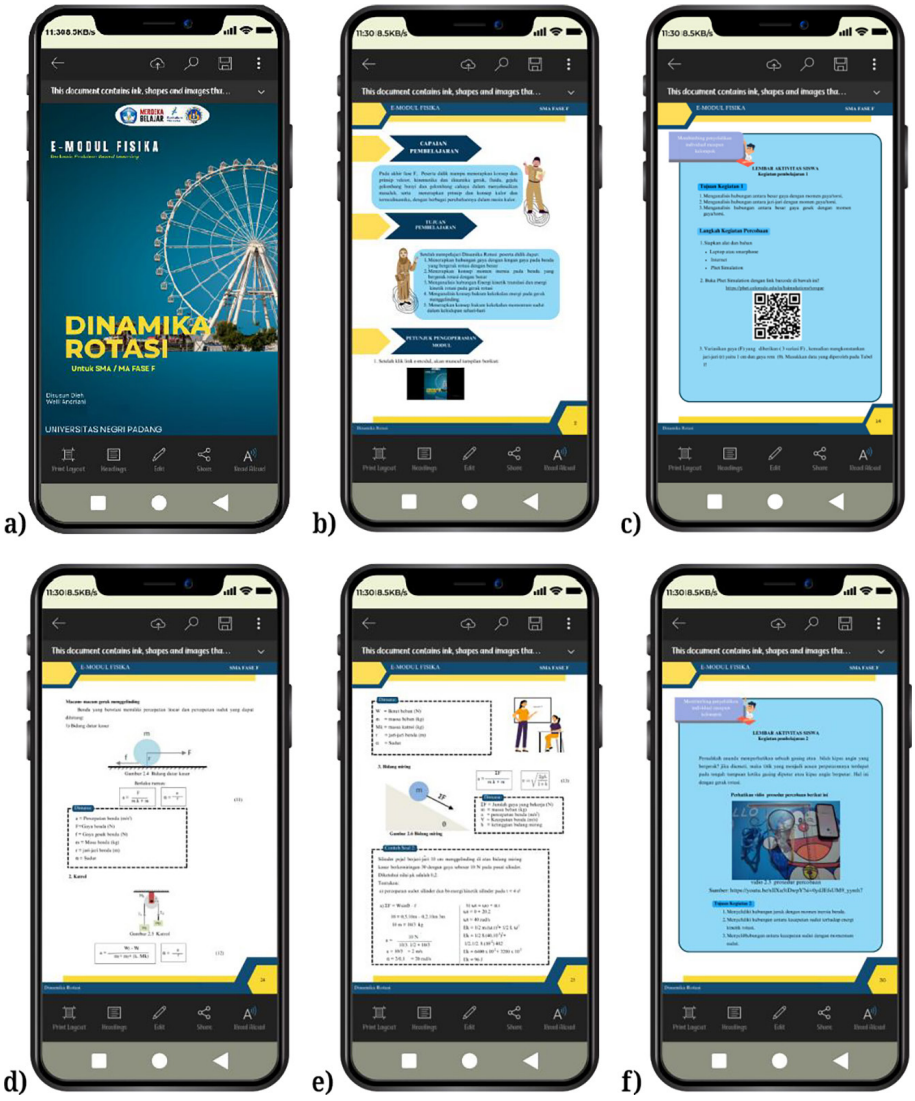


Fig. 3. (a) Cover, (b) Learning outcomes and objectives, (c) Student activity sheet with a QR code for a simulation, (d) Explanations and diagrams of rolling motion and a pulley, (e) Inclined-plane example and worked solution, (f) Student activity sheet with a procedure video and activity objectives

Figure 3 also shows that the e-module was designed to support the syntax of PBL. The content begins with student identity, pre-learning guidance, and instructions for using the module. The learning activities then move to contextual problem scenarios related to rotational dynamics, supported by visuals, instructional videos, animations, and interactive simulations. Students are guided through Student Activity Sheets to analyze problems, discuss possible solutions, and formulate conclusions. The module ends with reflection activities, references, and a short author profile.

The system interaction design is presented in Figure 4. The UML Use Case Diagram shows the relationship between students, instructors, and the e-module system. Students access learning content, engage with PBL problems, collaborate with peers, receive feedback, reflect on learning progress, and submit final solutions. Instructors design the PBL problems, monitor learning progress, evaluate student responses, and provide feedback. The e-module supports these interactions by organizing learning content, presenting PBL problem scenarios, and providing access to QR-linked multimedia resources. The teacher monitored student progress, while responses and final solutions were completed through the classroom procedures established during implementation.

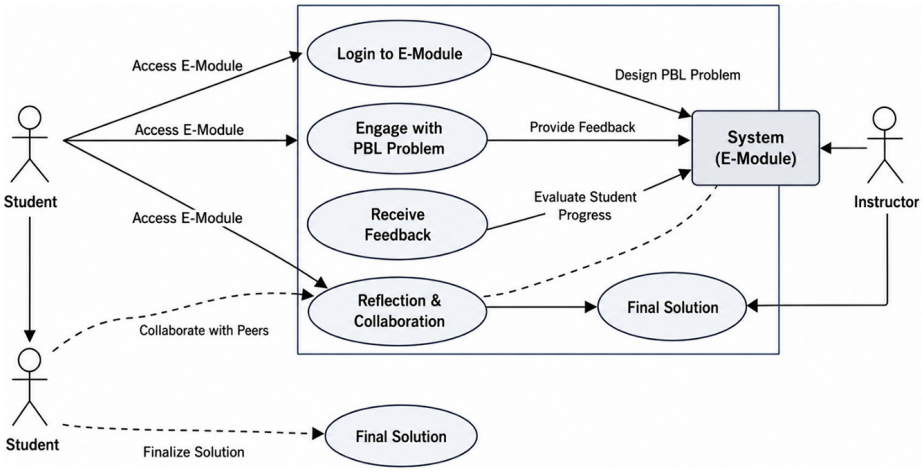


Fig. 4. Use case diagram

3.3 Develop

The Develop stage included expert validation, product revision, practicality testing, and effectiveness testing. After Prototype 1 was completed, the e-module was revised based on supervisory feedback to improve usability, visual consistency, instruction clarity, and alignment with the intended PBL learning flow. Expert validation was conducted by six physics lecturers from Universitas Negeri Padang. Practicality testing involved two physics teachers and 33 Grade 12 students from SMA Negeri 2 Padang. The effectiveness test was then conducted using pre-test and post-test scores from the same student group.

3.4 Validity test

The validity assessment covered five components of the e-module: material quality, learning design, graphics, software usability, and PBL integration. As presented in Table 4, all components obtained Aiken's V values above the minimum validity

threshold of 0.79. The overall mean Aiken's V coefficient was 0.89, indicating that the e-module met the validity criteria in terms of content accuracy, instructional organization, visual presentation, technical usability, and alignment with the PBL model.

Table 4. Results of the problem-based physics learning e-module validation

No	Assessment Components	Aiken's V	Description
1	Material Validation	0.90	Valid
2	Learning Design Validation	0.88	Valid
3	Graphics	0.93	Valid
4	Software Utilization	0.83	Valid
5	Integrated PBL Model	0.91	Valid
Overall Average		0.89	Valid

Among the assessed components, graphics obtained the highest Aiken's V value of 0.93, indicating strong expert agreement regarding the module's layout, readability, and visual consistency. Software usability received the lowest value of 0.83, although it remained above the validity threshold. This result suggests that the e-module was technically suitable for classroom implementation, while aspects such as navigation, mobile accessibility, and access to QR-linked media may still require further refinement. Overall, the validation findings confirm that the e-module was sufficiently valid to proceed to practicality and learning effectiveness tests.

3.5 Practicality test

The practicality test evaluated four aspects of the e-module: benefits, attractiveness, ease of media use, and clarity. As presented in Table 5, teachers rated the e-module as very practical, with an overall average score of 96.5%, whereas students rated it as practical, with an overall average score of 85.05%. Teacher ratings were consistently higher than student ratings across all assessed aspects. Teachers gave the highest scores to benefits and attractiveness, both reaching 98.0%, while students gave the highest score to ease of media use at 87.7%.

These findings indicate that teachers perceived the e-module as highly suitable for supporting classroom instruction and PBL activities. Students also responded positively, particularly to its accessibility and ease of use. However, the lower student ratings suggest that clear instructions, teacher guidance, and instructional scaffolding remain important during implementation. Overall, the results confirm that the e-module was feasible and practical for use in PBL-based physics learning.

Table 5. Results of the practicality test for the problem-based physics learning e-module

Aspect Assessment	Teacher Response		Student Response	
	Avg.%	Criteria	Avg.%	Criteria
Benefits	98.0	Very Practical	83.6	Practical
Attractiveness	98.0	Very Practical	83.6	Practical
Ease of Media Use	95.0	Very Practical	87.7	Very Practical
Clarity	95.0	Very Practical	85.3	Practical
Overall Average	96.5	Very Practical	85.05	Practical

3.6 Initial effectiveness of the PBL-based e-module

The initial effectiveness of the PBL-based e-module was evaluated by comparing students' achievement before and after the learning intervention. The pre-test was administered before students used the e-module, whereas the post-test was administered after they had completed the PBL-based learning activities. The analysis was conducted sequentially using descriptive statistics, the Shapiro–Wilk normality test, a paired-samples t-test, effect-size estimation, and normalized gain analysis.

Table 6. Descriptive statistics of pre- and post-test scores (N = 33)

Variable	N	Mean	SD	SE	Median	Min.	Max.	95% CI for Mean
Pre-test	33	53.39	6.22	1.08	55	42	66	[51.19, 55.60]
Post-test	33	77.24	6.53	1.14	77	64	90	[74.93, 79.56]

As shown in Table 6, students' mean score increased from 53.39 on the pre-test to 77.24 on the post-test, representing an average improvement of 23.85 points. The median score also rose from 55 to 77, while the minimum and maximum scores increased from 42 and 66 to 64 and 90, respectively, indicating an overall upward shift in achievement. The standard deviations remained relatively similar between the pre-test and post-test (6.22 and 6.53), suggesting that the improvement occurred without a substantial change in score variability. The relatively small standard errors and clearly separated 95% confidence intervals further indicate that the mean scores were estimated with adequate precision.

Table 7. Shapiro–Wilk normality test results for pre-test, post-test, and paired difference scores

Normality Test	Shapiro-Wilk *W*	*p*-Value	Decision ($\alpha = 0.05$)	Interpretation
Pre-test	0.970	0.480	Fail to reject H_0	No significant departure from normality
Post-test	0.962	0.287	Fail to reject H_0	No significant departure from normality
Post-test–pre-test difference scores	0.971	0.500	Fail to reject H_0	No significant departure from normality

As presented in Table 7, the Shapiro–Wilk test yielded $W = 0.970$, $p = 0.480$, for the pre-test scores and $W = 0.962$, $p = 0.287$, for the post-test scores. These results indicated no statistically significant departure from normality at either measurement occasion. The Shapiro–Wilk test showed no statistically significant departure from normality for the paired difference scores ($W = 0.971$, $p = 0.500$).

Table 8. Paired-samples t-test

Comparison	Mean Difference	*SD*	*SE*	*t*	df	*p*-Value	*95% CI*	*Cohen's* d_z *(95% CI)*
Post-test–Pre-test	23.85	4.5	0.78	30.44	32	< 0.001	[22.25, 25.44]	5.30 [3.96, 6.63]

After checking the paired difference scores for normality, we conducted a paired-samples t-test. As presented in Table 8, students achieved significantly higher post-test scores than pre-test scores, with a mean increase of 23.85 points, $SD = 4.50$, $SE = 0.78$, $t\ (32) = 30.44$, $p < 0.001$, 95% CI [22.25, 25.44]. The standardized mean

change was exceptionally large, *Cohen's* d_z = 5.30, 95% *CI* [3.96, 6.63]. These findings indicate substantial improvement in students' achievement following the intervention. However, because the study employed a one-group pre-test–post-test design without a control group, the result represents initial evidence of within-group improvement rather than definitive evidence of a causal intervention effect.

Table 9. N-gain analysis results

N	Mean N-Gain	N-Gain (%)	Minimum	Maximum	Category
33	0.52	51.75	0.33	0.72	Medium

As shown in Table 9, the mean N-gain score was 0.52, placing the overall learning improvement in the medium category. Individual N-gain scores ranged from 0.33 to 0.72, indicating that the magnitude of improvement varied among students. The positive minimum score shows that all participants recorded an increase between the pre-test and post-test.

Overall, the descriptive statistics, normality test, paired-samples t-test, effect-size estimate, and N-gain analysis provide consistent initial evidence of improvement in students' physics achievement after using the PBL-based e-module. Nevertheless, the findings should be interpreted within the limitations of the one-group design and should not be considered definitive evidence that the e-module alone caused the observed improvement.

4 DISCUSSION

The main contribution of this study extends beyond the development of a physics e-module by providing initial empirical evidence that a mobile-accessible, technology-supported PBL approach can be implemented in a public secondary-school context. The overall Aiken's V value of 0.89 indicates that the product met the expected standards of content accuracy, instructional design, visual presentation, software usability, and PBL integration. These results suggest that the Define, Design, and Develop stages produced an instructional resource that was pedagogically appropriate for rotational dynamics and rigid-body equilibrium and technically feasible for classroom use.

The practicality results further demonstrate the feasibility of implementation. Teachers rated the e-module as very practical, with an overall score of 96.5%, whereas students rated it as practical, with a score of 85.05%. This difference may reflect the distinct perspectives of the two groups. Teachers may have focused on instructional organization, classroom suitability, and support for PBL activities, while students may have been more sensitive to accessibility, task complexity, group participation, and the cognitive demands of contextual problem-solving. The student ratings therefore highlight the continuing need for clear instructions, structured collaboration, and timely teacher support.

The effectiveness analysis showed that the mean achievement score increased from 53.39 on the pre-test to 77.24 on the post-test, corresponding to a mean improvement of 23.85 points. The paired-samples t-test indicated a statistically significant within-group difference, while the mean N-gain of 0.52 represented a moderate level of improvement. These findings provide initial evidence that the e-module supported students' understanding of rotational dynamics and rigid-body equilibrium. However, the one-group pre-test–post-test design does not permit the observed

improvement to be attributed exclusively to the intervention. Teacher explanations, classroom interaction, prior knowledge, repeated exposure, and other contextual factors may also have contributed to the results.

The findings are consistent with research showing that interactive digital materials can address limitations of conventional instruction, particularly in subjects requiring visualization and structured reasoning [24], [25]. They also support previous studies indicating that PBL can promote deeper learning by connecting theoretical concepts with authentic problems [26], [27]. In the present study, contextual scenarios, activity sheets, visual explanations, QR-linked resources, simulations, and reflection activities formed a coherent instructional sequence that guided students in interpreting and solving abstract physics problems.

This structured support is particularly relevant because unequal participation, limited resources, and difficulty understanding abstract concepts remain common barriers in PBL-based science learning [28]–[30]. Rather than functioning as a digital repository, the e-module provided guided problem interpretation, collaborative worksheets, and reflection prompts that supported students throughout the learning process [31]–[33]. Such scaffolding is important in rotational dynamics, where torque, moment of inertia, rotational kinetic energy, angular momentum, and equilibrium require spatial visualization, mathematical reasoning, and multi-step analysis. Previous studies have similarly linked students' conceptual difficulties to limited contextualization and insufficient access to interactive resources [34], [35].

The results also clarify the technological contribution of the product. Digital resources are more likely to support problem-solving and critical thinking when they are aligned with explicit instructional purposes and accompanied by adequate scaffolding [36]–[38]. The e-module was not a native Android application or an automated learning-management system. Instead, it provided mobile-readable content and access to external multimedia and browser-based simulations, while teachers remained responsible for monitoring progress, managing responses, and providing feedback. This configuration may be useful in settings where smartphones are more accessible than computers, although its effectiveness depends on device availability, internet connectivity, digital literacy, and teacher readiness.

The instructional architecture may also be transferable to online and mobile engineering education because it combines contextual problems, multimedia resources, simulations, collaborative tasks, feedback, and reflection without requiring specialized software or laboratory infrastructure. Its mechanics content is conceptually relevant to introductory biomedical engineering and biomechanics, including the analysis of human movement, joint mechanics, lever systems, prosthetic components, rehabilitation mechanisms, and assistive devices. Nevertheless, these applications were not examined directly and should be treated as potential directions for further investigation rather than established outcomes of the present study.

5 IMPLICATIONS AND LIMITATIONS

The findings indicate that effective digital learning resources require systematic alignment among content, learning objectives, contextual problems, visual explanations, simulations, student activities, assessment tasks, and PBL stages. For topics such as rotational dynamics, this alignment can provide the conceptual and visual scaffolding needed to analyze complex physical systems. Practical implementation should also include clear usage instructions, structured group-work procedures,

teacher-facilitation guidance, and accessible alternatives for students who experience limitations in device compatibility or internet connectivity. In online and mobile engineering contexts, the same design principles may support learning without requiring a native application, provided that media-loading efficiency, accessibility, disciplinary authenticity, and instructor preparation are addressed.

Several limitations constrain the interpretation and transferability of the findings. The absence of a control group prevents a definitive causal conclusion, while the sample of 33 students from a single school limits generalizability. The development process ended at the Define, Design, and Develop stages, so broader dissemination and implementation across different settings were not evaluated. The effectiveness assessment focused on cognitive achievement and did not examine critical thinking, collaboration, engagement, problem-solving processes, or long-term retention. The proposed relevance to engineering and biomedical engineering also remains conceptual because the module was not tested in those disciplines.

Reliability coefficients were not estimated for the student practicality questionnaire or the physics achievement test, and internal consistency was not calculated for the teacher questionnaire because only two teachers participated. Although all instruments underwent expert content review, the absence of reliability estimates limits conclusions about score consistency. Future studies should involve control or comparison groups, larger and more diverse samples, extended observation periods, and broader outcome measures. They should also assess questionnaire reliability using Cronbach's alpha or McDonald's omega, evaluate the dichotomously scored achievement test using KR-20, and examine the module's applicability in engineering and biomedical engineering settings.

6 CONCLUSION AND FUTURE WORK

This study developed and evaluated an Android-accessible PBL-based e-module for rotational dynamics and rigid-body equilibrium using the Define, Design, and Develop stages of the 4D framework. The mobile-readable module integrated contextual problems, visual explanations, QR-linked multimedia, browser-based simulations, collaborative activities, and reflection within a teacher-facilitated learning process. The product met the validity and practicality criteria, with an overall Aiken's V of 0.89 and practicality scores of 96.5% from teachers and 85.05% from students.

Students' mean achievement score increased from 53.39 to 77.24, and the paired-samples t-test indicated a significant within-group improvement, $t(32) = 30.44$, $p < 0.001$. The mean N-gain of 0.52 indicated a moderate level of learning improvement. These findings provide initial evidence that the e-module can support learning in rotational dynamics and rigid-body equilibrium. However, because the study used a one-group pre-test–post-test design, the observed improvement cannot be attributed exclusively to the intervention.

Future research should employ control or comparison groups, larger and more diverse samples, and longer observation periods to assess causal effects, generalizability, and learning retention. Further evaluation should examine critical thinking, collaboration, engagement, and problem-solving processes, complete the Disseminate stage, and establish instrument reliability. Adapted versions of the module should also be tested in engineering, biomedical engineering, and biomechanics contexts, alongside improvements in navigation, offline access, device compatibility, media-loading efficiency, and teacher-facilitation support.

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