



DEVELOPMENT OF A STEM-BASED PHYSICS LEARNING HANDBOOK FOR ENHANCING UNDERGRADUATE STUDENTS' LITERACY AND NUMERACY SKILLS

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Abstract: This study aimed to develop a STEM-based Physics Learning Management Handbook to enhance students' literacy and numeracy skills and examine its feasibility and effectiveness. Literacy indicators included concept identification, information interpretation, phenomenon analysis, and scientific communication, while numeracy indicators covered mathematical application, data interpretation, and contextual physics problem-solving. The study employed a Research and Development (R&D) approach using the ADDIE model. Participants involved experts, lecturers, and 144 physics education students at Universitas Negeri Jakarta during the 2025/2026 academic year. Instrument validation using point-biserial correlation indicated that 30 of 33 literacy items and 30 of 32 numeracy items were valid. Reliability testing using KR-20 produced coefficients of 0.89 for literacy and 0.87 for numeracy, indicating high internal consistency. Product feasibility scores from material, media, and instructional experts showed that the developed product was highly feasible. The Hake N-gain analysis demonstrated high improvement in literacy (0.73) and numeracy (0.70), while Cohen's d analysis indicated large effect sizes for literacy (0.86) and numeracy (0.82). These findings demonstrate that the developed book effectively improved students' competencies and supported SDG 4 on quality education.

Keywords: Physics Learning Management Handbook, Literacy Skills, Numeracy Skills.

INTRODUCTION:

Physics education plays a strategic role in preparing students with the competencies required in the twenty-first century, particularly critical thinking, problem-solving, scientific reasoning, and quantitative analysis skills. In contemporary educational contexts, students are expected not only to master scientific concepts but also to interpret information critically, analyze scientific phenomena systematically, and apply mathematical reasoning to solve contextual problems. Consequently, literacy and numeracy have become fundamental competencies in physics learning because physics inherently integrates scientific communication, conceptual interpretation, data analysis, and mathematical representation (OECD, 2023; UNESCO, 2022).

Scientific literacy refers to students' ability to interpret scientific information, evaluate evidence critically, apply conceptual understanding, and communicate scientific explanations appropriately in various contexts. In physics education, scientific literacy includes explaining physical phenomena, analyzing scientific evidence, and connecting scientific concepts with real-world situations (OECD, 2023; UNESCO, 2022). Numeracy is not limited to mathematical calculation but also includes quantitative reasoning, interpretation of data representations, and the application of mathematical thinking in real-life scientific contexts (Geiger et al., 2015; OECD, 2023).



Meanwhile, numeracy refers to the ability to apply mathematical reasoning, interpret quantitative information, and analyze data to solve contextual problems. Within physics learning, numeracy involves interpreting graphs and tables, analyzing relationships among variables, conducting quantitative calculations, and applying mathematical reasoning in scientific situations (OECD, 2023; Rahman et al., 2023). These competencies are increasingly recognized as important learning outcomes because they support students in developing problem-solving abilities, critical thinking, and adaptive skills required in rapidly evolving scientific and technological environments.

Despite their importance, numerous studies have reported that students' literacy and numeracy competencies remain relatively low, particularly in science and physics learning. Results from the Programme for International Student Assessment (PISA) 2022 indicated that Indonesian students' performance in reading, mathematics, and science was still significantly below the OECD average (OECD, 2023). Students frequently experience difficulties in interpreting scientific information, connecting theoretical concepts to real-life phenomena, analyzing quantitative data, and solving contextual problems involving mathematical reasoning. These findings demonstrate the urgent need for innovative learning resources capable of supporting conceptual understanding while simultaneously strengthening students' literacy and numeracy competencies in physics learning.

One of the major challenges in physics instruction is the limited availability of structured learning resources that explicitly integrate literacy and numeracy competencies into physics classroom management and instructional practices. Existing classroom practices are often dominated by teacher-centered instruction, fragmented learning materials, and concept-oriented teaching approaches that provide insufficient opportunities for students to engage actively in scientific communication, data interpretation, and contextual problem-solving activities (UNESCO, 2022). As a result, students tend to memorize formulas and concepts without developing deeper scientific understanding and quantitative reasoning abilities. Such conditions indicate that effective learning management is crucial in creating meaningful, student-centered, and competency-oriented physics learning environments.

Learning management in physics education refers to the systematic process of planning, organizing, implementing, and evaluating learning activities to achieve instructional objectives effectively. Effective learning management should encourage active student participation, contextual learning experiences, inquiry-based activities, and authentic assessments that facilitate literacy and numeracy development (Johnson et al., 2020; Robbins & Coulter, 2018). Therefore, the development of learning resources that integrate instructional management principles with literacy- and numeracy-oriented activities is highly necessary to improve the quality of physics learning.

One potential innovation to address these challenges is the development of a Physics Learning Management Handbook based on STEM education. STEM (Science, Technology, Engineering, and Mathematics) education emphasizes interdisciplinary learning, problem-solving, inquiry, and the application of scientific concepts to real-world situations. Previous studies have demonstrated



that STEM-based learning positively influences students' scientific literacy, critical thinking, creativity, and quantitative reasoning skills (Serevina et al., 2025; OECD, 2023). Through STEM integration, students are encouraged to investigate phenomena, analyze data, design solutions, and apply mathematical reasoning in meaningful contexts. Therefore, STEM-based learning is considered highly relevant for improving literacy and numeracy competencies in physics education. Recent studies emphasize that STEM education should integrate interdisciplinary inquiry, engineering design, and authentic problem-solving activities to promote meaningful learning experiences and twenty-first century competencies (Margot & Kettler, 2019; Li et al., 2020).

A Physics Learning Management Handbook is a structured learning resource designed to support teachers and students in organizing, implementing, and evaluating learning activities systematically. The book integrates instructional planning, STEM-oriented learning activities, literacy tasks, numeracy exercises, scientific investigations, and formative assessment within a unified instructional framework. Such integration enables students to engage actively in scientific inquiry while simultaneously developing their literacy and numeracy skills through contextual and problem-based learning experiences. In addition, the learning resource provides guidance for teachers in implementing more structured, meaningful, and student-centered learning processes.

Several previous studies have investigated the implementation of STEM learning, project-based learning, digital modules, and contextual learning materials in improving students' competencies in science education. These studies generally reported positive impacts on students' conceptual understanding, critical thinking, scientific literacy, and quantitative reasoning abilities (OECD, 2023; UNESCO, 2022). However, limited studies specifically focus on the development of Physics Learning Management Handbook that systematically integrate literacy and numeracy competencies within a STEM-based learning framework. In this study, POAC was utilized as an instructional management framework to organize STEM learning implementation. Most existing studies primarily emphasize instructional models or digital media without providing comprehensive learning management resources capable of guiding both teachers and students in implementing literacy- and numeracy-oriented physics learning. The instructional management framework adopted in this study was based on the POAC principles consisting of Planning, Organizing, Actuating, and Controlling. POAC provides a systematic managerial framework for organizing instructional processes, monitoring learning implementation, and evaluating learning outcomes effectively in STEM-based educational environments (Robbins & Coulter, 2018; Daft, 2022).

Accordingly, the novelty of this study lies in the development of a STEM-Based Physics Learning Management Handbook that integrates literacy and numeracy competencies into a structured learning management system. Unlike previous learning resources, the developed product combines instructional planning, STEM-oriented investigations, contextual literacy activities, numeracy-based problem-solving exercises, and reflective learning evaluations within one integrated framework. This integration is expected to support meaningful learning experiences and simultaneously strengthen students' scientific literacy and quantitative reasoning skills.



The urgency of this research is closely related to the increasing global demand for quality education that equips students with essential twenty-first century competencies. This study also contributes to the implementation of Sustainable Development Goal (SDG) 4 concerning quality education, particularly in improving literacy, numeracy, critical thinking, and lifelong learning skills (United Nations, 2015). The development of a STEM-Based Physics Learning Management Handbook is therefore expected to provide innovative and effective learning resources that support teachers in implementing contextual and student-centered physics instruction while improving students' literacy and numeracy competencies.

STEM-based physics learning is an instructional approach that integrates science, technology, engineering, and mathematics to help students understand physics concepts through contextual problem-solving activities. A synthesis of recent studies indicates that STEM-oriented physics instruction can enhance twenty-first century competencies, including critical thinking, creativity, collaboration, and problem-solving skills, because students are actively involved in designing and testing scientific solutions (Le et al., 2023; Roslina et al., 2022). In practice, Project-Based Learning and Inquiry Learning are commonly applied within STEM-based physics learning since both approaches support experimentation, engineering design, and the integration of technology into classroom activities (Winarti et al., 2021; Ghorbiy et al., 2024).

Several important indicators characterize STEM-based physics learning. These include: (1) the ability to integrate scientific and mathematical concepts in solving physics-related problems; (2) the use of technology and digital media during scientific investigations; (3) engineering design skills such as planning, testing, and evaluating products or solutions; (4) critical and creative thinking abilities; and (5) collaboration and scientific communication skills (Anggreiny et al., 2023; Le et al., 2023). In physics education, these indicators are frequently implemented in topics such as fluids, waves, optics, and heat transfer through STEM project activities that encourage students to develop innovative solutions for real-world issues (Ghorbiy et al., 2024; Roslina et al., 2022).

In addition to improving students' conceptual understanding of physics, STEM-based instruction also contributes positively to learning motivation, scientific literacy, and higher-order thinking skills (HOTS). Findings from meta-analyses and systematic literature reviews demonstrate that integrating STEM into physics education is effective in preparing students for the demands of the twenty-first century and the Industrial Revolution 4.0 era (Rahman et al., 2023; Winarti et al., 2021). Therefore, STEM-based physics learning should be designed through authentic activities, appropriate technological integration, and project-oriented assessment to ensure that the objectives of modern physics education can be achieved effectively (Le et al., 2023; Anggreiny et al., 2023).

Based on these considerations, this study aims to: develop a STEM-Based Physics Learning Management Handbook to enhance students' literacy and numeracy skills; and examine the effectiveness of the developed product in improving students' literacy and numeracy competencies in physics learning.



METHODOLOGY:

This study employed a Research and Development (R&D) approach using a systematic instructional design framework consisting of five stages: Analysis, Design, Development, Implementation, and Evaluation. The R&D approach was selected because it facilitates the development, validation, and evaluation of educational products intended to improve learning quality and students' competencies in contextual learning environments (Creswell & Guetterman, 2019; Johnson et al., 2020). The product developed in this study was a STEM-based Physics Learning Management Handbook designed to support students' literacy and numeracy development in physics learning activities, particularly in contextual physics problem-solving and quantitative reasoning tasks (Li et al., 2020; Le et al., 2023).

The study and research product trial was conducted at Universitas Negeri Jakarta during the 2025/2026 academic year and involved 144 students participating in physics learning activities. The participants were selected purposively based on their enrollment in physics courses related to Newtonian mechanics (material of physics learning) and their involvement in STEM-based learning implementation. In addition, the product feasibility validation process involved material experts, media experts, and learning experts to evaluate the appropriateness of the developed product in terms of content quality, instructional presentation, language clarity, visual design, and learning relevance. Expert validation was conducted to ensure that the developed learning product met instructional standards and supported effective STEM-based physics learning implementation (Creswell & Guetterman, 2019; Johnson et al., 2020).

The percentage of positive responses is presented in Figure 1.

Percentage of Positive Responses (Agree + Strongly Agree)

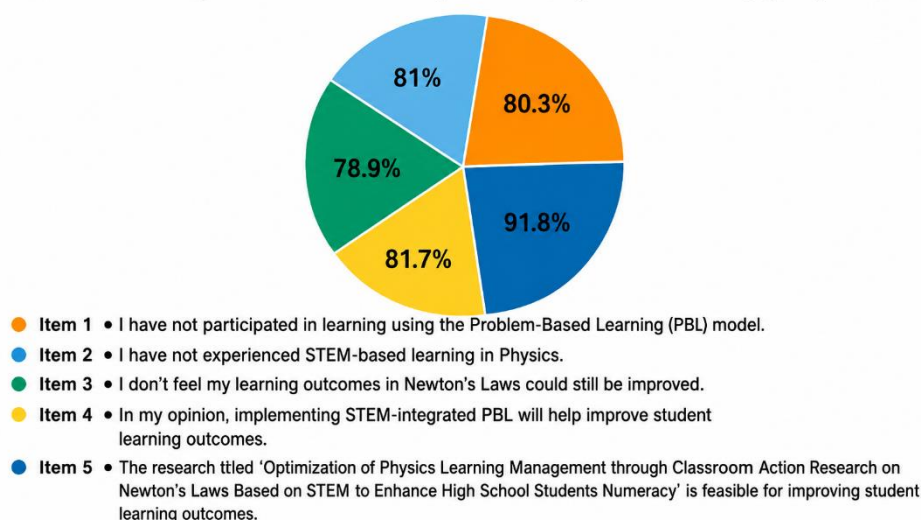


Figure 1. Percentage of Positive Responses

The development procedure adopted the ADDIE instructional design model consisting of Analysis, Design, Development, Implementation, and Evaluation stages. During the Analysis stage, preliminary observations and needs assessments were conducted to identify students' difficulties related to literacy and numeracy skills in physics learning. The findings showed that students experienced challenges in interpreting scientific information, applying mathematical



reasoning, and solving contextual physics problems. The Design stage involved preparing the framework of the STEM-based Physics Learning Management Handbook, formulating learning objectives, designing STEM-oriented learning activities, and developing literacy and numeracy assessment instruments. The Development stage focused on producing and revising the initial prototype through expert validation processes. The Implementation stage involved limited and broader trials of the developed product in physics learning activities, while the Evaluation stage examined product feasibility, validity, reliability, and effectiveness based on students' learning outcomes and expert judgments (Creswell & Guetterman, 2019; Johnson et al., 2020).

The ADDIE model was selected because it provides a systematic and iterative framework suitable for developing instructional products integrating STEM pedagogy, literacy enhancement, and numeracy-oriented learning activities.

The primary product developed in this study was a STEM-based Physics Learning Management Handbook designed to support systematic physics instruction through contextual and interdisciplinary learning experiences. Physics learning management in this study refers to structured instructional processes involving planning, organizing, implementing, and evaluating STEM-oriented physics learning activities. The developed framework integrated science, technology, engineering, and mathematics into inquiry-based and problem-solving activities. The indicators of the Physics Learning Management Handbook included: (1) planning STEM-based instructional objectives and strategies, (2) organizing learning materials and classroom activities, (3) implementing inquiry and contextual problem-solving activities, (4) integrating scientific and mathematical concepts into technological and engineering contexts, and (5) evaluating students' literacy and numeracy achievement (Kelley & Knowles, 2016; Li et al., 2020).

Scientific literacy in this study refers to students' ability to interpret scientific information, analyze scientific phenomena, apply conceptual understanding, and communicate scientific explanations effectively in contextual situations. The literacy indicators consisted of: (1) identifying scientific concepts, (2) interpreting scientific information, (3) analyzing scientific phenomena, and (4) communicating scientific explanations. These indicators were integrated into STEM-based physics learning activities and assessment instruments to examine students' literacy development throughout the implementation process (OECD, 2023; UNESCO, 2022).

Numeracy in this study refers to students' ability to apply mathematical reasoning, interpret quantitative information, analyze data, and solve contextual problems related to physics learning situations. The numeracy indicators included: (1) applying mathematical concepts in physics problem-solving, (2) interpreting tables, graphs, and quantitative data, (3) conducting quantitative calculations and analysis, and (4) solving contextual physics problems systematically. These indicators were incorporated into STEM-based learning activities and assessment instruments developed within the Physics Learning Management Handbook framework (OECD, 2023; Rahman et al., 2023).



The data collected in this study consisted of primary and secondary data. Primary data included expert validation results, students' literacy and numeracy pre-test and post-test scores, and responses from learning implementation activities. Secondary data were obtained from books, journal articles, and previous studies related to STEM learning, literacy, numeracy, instructional design, and educational product development (Creswell & Creswell, 2018; Sugiyono, 2019).

Table 1. Indicators of Physics Learning Management

POAC	INDICATORS	SCALE
Planning	Lesson plan alignment with STEM principles; clarity of learning objectives; integration of numeracy tasks	1-4
Organizing	Classroom organization; group task distribution; availability of learning resources	1-4
Actuating	Implementation of STEM activities; student engagement; facilitation of inquiry and problem-solving	1-4
Controlling	Monitoring of learning progress; feedback provision; product revision and improvement between formative evaluation	1-4

The research instruments consisted of expert validation sheets, literacy tests, numeracy tests, and student response questionnaires. The literacy instrument initially comprised 33 multiple-choice items, while the numeracy instrument consisted of 32 items related to physics learning contexts. Instrument validity was examined using the point-biserial correlation technique to determine the discriminatory power of dichotomous test items by correlating individual item scores with total test scores (Creswell & Guetterman, 2019; OECD, 2023). Items with a point-biserial coefficient ($r_{pb} \geq 0.30$) were categorized as valid. The analysis results indicated that 30 literacy items and 30 numeracy items fulfilled the validity criteria and were retained for subsequent analysis.

Instrument reliability was analyzed using internal consistency testing for dichotomous objective items to examine the stability and consistency of the developed literacy and numeracy instruments. Reliability analysis was conducted to ensure that the assessment instruments consistently measured students' competencies in STEM-based physics learning contexts (Creswell & Guetterman, 2019; OECD, 2023). The reliability coefficients obtained were 0.89 for the literacy instrument and 0.87 for the numeracy instrument, indicating high reliability and strong internal consistency according to educational measurement standards.

Product feasibility was evaluated through expert judgment involving material experts, media experts, and learning experts using a four-point Likert scale. The evaluation covered content accuracy, instructional quality, language clarity, visual presentation, STEM integration, and usability in physics learning contexts. The feasibility assessment results showed scores of 85 from material experts, 90 from media experts, and 87 from learning experts, indicating that the developed product was categorized as highly feasible for implementation in physics education. Expert-based feasibility evaluation is considered important in educational product development to ensure instructional relevance, usability, and alignment with learning objectives prior to broader implementation (Creswell & Guetterman, 2019; Johnson et al., 2020).



Prior to conducting effectiveness analysis, data normality was examined using the Shapiro–Wilk test. The analysis showed that several datasets were not normally distributed ($p < 0.05$); therefore, non-parametric analysis using the Wilcoxon Signed-Rank Test was additionally employed to examine differences between pre-test and post-test scores.

The effectiveness of the developed Physics Learning Management Handbook was analyzed using the normalized gain (N-gain) test to measure students' improvement between pre-test and post-test scores. The N-gain analysis was employed to determine the extent of learning improvement by comparing the actual gain obtained with the maximum possible gain. The interpretation criteria categorized the improvement into low, medium, and high levels based on the obtained gain scores in educational intervention studies (OECD, 2023; Rahman et al., 2023). N-Gain Category: if $g < 0,30$ = Low, if $0,30 \leq g < 0,70$ = Medium, if $g \geq 0,70$ = High.

The analysis results showed N-gain values of 0.73 for literacy and 0.70 for numeracy, indicating high improvement after the implementation of the developed STEM-based learning management handbook in physics learning activities. The implementation process of the STEM-Based Physics Learning Management Handbook for enhancing students' literacy and numeracy is presented in Figure 2.



Figure 2. Implementation of a STEM-Based Physics Learning Management Handbook for enhancing students' literacy and numeracy

To examine the magnitude of the instructional impact, effect size analysis was conducted using Cohen's d statistic to evaluate the practical significance of the intervention in STEM-based physics learning. The analysis compared the mean differences between pre-test and post-test scores relative to the pooled standard deviation to determine the strength of the educational intervention. Effect size interpretation categorized the results into small, medium, and large effect levels to provide a clearer understanding of the effectiveness of the developed learning management framework in improving students' literacy and numeracy competencies (Le et al., 2023; Li et al., 2020). The effect size analysis strengthened the interpretation of the instructional effectiveness of the STEM-based Physics Instruction Management Handbook in supporting students' conceptual understanding, quantitative reasoning, and contextual problem-solving abilities in physics learning activities.



RESULTS AND DISCUSSION:

Development of STEM-Based Physics Learning Management Handbook Using the ADDIE Model

This study developed a Physics Learning Management Handbook designed to optimize students' literacy and numeracy skills in STEM-based physics learning. The development process adopted the ADDIE model consisting of five stages: Analysis, Design, Development, Implementation, and Evaluation. The STEM orientation in this study emphasized the integration of physics concepts with contextual problem-solving, mathematical reasoning, scientific literacy, and technology-supported learning activities.

The stages of the ADDIE model implemented in this study are presented in Figure 3.

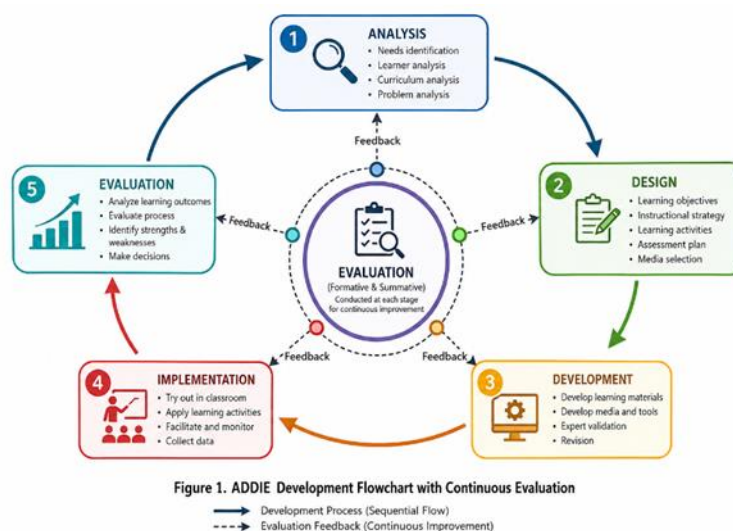


Figure 3. ADDIE Development Flowchart

1. Analysis Stage

The analysis stage was conducted to identify learning problems, students' needs, curriculum demands, and the characteristics of STEM-based physics learning. Preliminary observations indicated that students experienced difficulties in interpreting physical phenomena quantitatively, analyzing scientific information, and applying mathematical reasoning in contextual physics problems. Existing learning resources were still dominated by theoretical explanations and procedural exercises, with limited integration between literacy and numeracy skills.

Furthermore, interviews with physics teachers revealed that learning management practices had not yet optimally integrated STEM approaches into classroom instruction. Therefore, the development of a Physics Learning Management Handbook was considered necessary to provide systematic instructional guidance emphasizing literacy, numeracy, and contextual STEM learning.

2. Design Stage

At the design stage, the structure and components of the Physics Learning Management Handbook were planned systematically. The book was designed to contain:

- 1) Learning objectives aligned with literacy and numeracy indicators;
- 2) STEM-integrated instructional scenarios;
- 3) Contextual physics activities and experiments;
- 4) Scientific literacy exercises;



- 5) Numeracy-oriented problem-solving tasks;
- 6) Assessment rubrics;
- 7) Product revision and evaluation activities.

The literacy indicators developed in this study included:

- identifying scientific concepts,
- interpreting information,
- analyzing physical phenomena, and
- communicating scientific ideas.

Meanwhile, numeracy indicators included:

- applying mathematical concepts,
- interpreting quantitative data, and
- solving contextual physics problems.

The learning materials focused on Physics learning and their applications in daily life through STEM-integrated activities emphasizing scientific inquiry, engineering design, and quantitative reasoning.

3. Development Stage

At the development stage, the initial prototype of the Physics Learning Management Handbook was produced and validated by experts consisting of material experts, media experts, and instructional experts.

The product validation results are presented in Table 2.

Table 2. Product Validation Results

Validator	Score	Category
Material Expert	85	Very Feasible
Media Expert	90	Very Feasible
Learning Expert	87	Very Feasible

The validation results indicate that the developed Physics Learning Management Handbook met the criteria for feasibility in terms of content accuracy, instructional design, visual presentation, language clarity, and STEM integration. Material experts emphasized that the developed book successfully integrated conceptual physics understanding with literacy and numeracy competencies. Media experts highlighted the systematic layout and readability of the book, while instructional experts emphasized the suitability of the instructional flow with STEM-oriented learning principles.

The novelty of this study lies in the integration of literacy and numeracy competencies within a physics learning management framework using a STEM approach. Previous studies mainly focused on STEM modules or digital learning media emphasizing conceptual understanding and problem-solving separately (English, 2017; Li et al., 2020; Le et al., 2023). In contrast, this study specifically developed a learning management handbook that systematically integrates literacy,



numeracy, instructional management, and STEM-based physics learning into one comprehensive instructional product (Kelley & Knowles, 2016; Li et al., 2020).

Prior to analyzing students' numeracy improvement, the quality of the research instrument was examined through item validity testing using the point-biserial correlation method. This analysis was conducted to ensure that each test item accurately measured students' numeracy skills in the context of Physics learning. The result of item validity test can be seen at Table 3.

Table 3. Results of Item Validity Test

Item	r_{pb}	Significance	Validity Result
1, 2, 3, 4, 5, 6, 7, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30	0,33; 0,35; 0,38; 0,40; 0,43; 0,36; 0,34; 0,36; 0,42; 0,46; 0,49; 0,51; 0,36; 0,52; 0,52; 0,33; 0,39; 0,45; 0,35; 0,37; 0,41; 0,33; 0,42; 0,51; 0,52; 0,48; 0,46; 0,34; 0,39; 0,50	Significant	Valid
8, 9, 10	0,15; 0,18; 0,20	Not Significant	Not Valid/Drop



The results indicate that thirty out of thirty three items met the validity criterion ($r_{pb} \geq 0.30$), while three items were excluded from further analysis. Valid items were subsequently used to measure students' numeracy improvement reliably and consistently in STEM-based physics learning contexts (Creswell & Guetterman, 2019; OECD, 2023).

The Wilcoxon Signed-Rank Test revealed a statistically significant difference between the paired pre-test and post-test scores ($p < 0.001$), indicating that the implementation of the STEM-based Physics Learning Management Handbook contributed significantly to the improvement of students' numeracy performance in physics learning activities. Furthermore, the average normalized gain (N-gain=0.71) was categorized as high, reflecting substantial learning improvement and stronger quantitative reasoning abilities following the implementation of the developed learning management framework (OECD, 2023; Rahman et al., 2023).

A. Instrument Testing Results

1) Literacy Instrument Validity Test

The literacy instrument consisted of 33 multiple-choice items. Item validity was tested using the point-biserial correlation method, and the result can be seen at table 4.

Table 4. Result of Literacy Instrument Validity Test

Category	Number of Items
Valid	30
Invalid/Drop	3

The analysis showed that 30 out of 33 literacy items met the validity criterion ($r_{pb} \geq 0.30$), while three items were excluded from further analysis because they did not meet the minimum correlation requirement.

The valid literacy items reflected students' abilities in scientific concept identification, interpretation of scientific information, analysis of physical phenomena, and communication of scientific reasoning.

2) Literacy Instrument Reliability Test

The reliability test for the literacy instrument was conducted using the KR-20 formula.

$$KR - 21 = \frac{k}{k - 1} \left(1 - \frac{M(k - M)}{kS^2} \right)$$

The reliability coefficient obtained was:

$$KR - 20 = 0.89$$

The result indicates that the literacy instrument had very high reliability, meaning the instrument consistently measured students' literacy abilities.

3) Numeracy Instrument Validity Test

The numeracy instrument consisted of 32 items tested using the point-biserial correlation method. The result can be seen at table 5.

**Table 5.** Result of Numeracy Instrument Validity Test

Category	Number of Items
Valid	30
Invalid/Drop	2

The analysis showed that 30 items fulfilled the validity requirement, while two items were excluded due to low discrimination indices. The valid items successfully measured students' abilities in mathematical application, data interpretation, and contextual quantitative reasoning in physics learning.

4) Numeracy Instrument Reliability Test

The reliability coefficient for the numeracy instrument was analyzed using KR-20.

$$KR - 21 = \frac{k}{k - 1} \left(1 - \frac{M(k - M)}{kS^2} \right)$$

The obtained coefficient was:

$$KR - 20 = 0.87$$

This result indicates that the numeracy instrument had high internal consistency and reliability.

The observed improvement in numeracy skills is particularly relevant in physics learning contexts, which are frequently characterized by abstract concepts and difficulties in connecting conceptual understanding with mathematical representations. Previous studies have shown that students commonly experience challenges in interpreting relationships among force, motion, and acceleration through graphical and quantitative analysis in physics learning (Li et al., 2020; Roslina et al., 2022). Through STEM-integrated learning activities, students in this study were encouraged to analyze motion data, interpret force relationships quantitatively, and apply physics concepts in contextual problem-solving situations. These learning experiences contributed to strengthening the relationship between conceptual understanding, scientific reasoning, and quantitative problem-solving abilities in physics learning environments (Le et al., 2023; Serevina et al., 2025).

The improved learning outcomes observed in this study are aligned with systematic learning management practices that emphasize instructional planning, implementation, monitoring, and evaluation processes in STEM-based physics learning environments. Effective learning management enables educators to organize contextual learning activities, monitor student engagement, and implement instructional improvements based on students' learning progress and performance data (Johnson et al., 2020; Li et al., 2020). In this study, formative instructional evaluation enabled the identification of learning difficulties and supported targeted improvements in STEM-based learning activities, resulting in increased student participation, more active classroom engagement, and stronger numeracy-related discussions during physics learning processes (Le et al., 2023; Roslina et al., 2022).

Furthermore, the findings indicate that STEM-based learning becomes increasingly effective as students become more familiar with interdisciplinary approaches that emphasize physics learning management handbook. As students' understanding of the STEM learning framework improved, their ability to apply numerical reasoning in physics contexts also developed more



significantly. This finding is consistent with previous studies reporting that STEM-oriented learning enhances students' numeracy, analytical thinking, and contextual problem-solving skills through interdisciplinary learning experiences (English, 2017; Rahman et al., 2023; Roslina et al., 2022).

4. Implementation Stage

The implementation stage involved 144 physics education students at Universitas Negeri Jakarta in 2026. The Physics Learning Management Handbook was implemented in STEM-based physics learning focused on Physics learning.

The learning activities emphasized:

- scientific literacy development,
- contextual quantitative reasoning,
- data analysis,
- mathematical modeling,
- collaborative problem-solving,
- and technology-supported physics learning.

Students participated in STEM-oriented activities involving interpretation of motion phenomena, analysis of force relationships, and application of physics learning in contextual engineering situations. The developed learning management handbook functioned not merely as teaching material but also as a systematic instructional management guide covering planning, organizing, implementation, and assessment processes within the developed STEM-based instructional framework. The final version of the developed Physics Learning Management Handbook was distributed in digital format and can be accessed through the following link:

https://drive.google.com/file/d/187G_g5tsaGug1SyZyv5wVrYXUk8MMLOC/view?usp=drivesdk

5. Evaluation Stage

The evaluation stage consisted of formative evaluation through expert validation and summative evaluation through field implementation results. The evaluation stage examined the effectiveness of the developed product in improving students' literacy and numeracy skills.

A. N-Gain Analysis

The normalized gain test was conducted using Hake's formula.

$$g = \frac{Posttest - Pretest}{Maximum\ Score - Pretest}$$

The N-Gain of Students' Numeracy Skills can be seen at table 6.

**Table 6.** N-Gain of Students' Numeracy Skills

No.	Indikator Numeracy	N-Gain	Category
1.	Mathematical Application	0.68	Medium
2.	Data Interpretation	0.71	High
3.	Contextual Physics Problem Solving	0.72	High
4.	Quantitative Reasoning	0.69	Medium
Total		0.70	High

The N-Gain of Students' Literacy Skills can be seen at table 7.

Table 7. N-Gain of Students' Literacy Skills

No.	Indikator Numeracy	N-Gain	Category
1.	Concept Identification	0.71	High
2.	Information Interpretation	0.72	High
3.	Phenomenon Analysis	0.75	High
4.	Scientific Communication	0.74	High
Total		0.70	High

The improvement in students' numeracy skills can be theoretically explained through the POAC learning management framework. During the planning phase, learning objectives and STEM tasks were explicitly designed to target numeracy indicators such as data interpretation, proportional reasoning, and mathematical modeling. In the organizing phase, interdisciplinary STEM learning activities were structured to integrate physics concepts with mathematical and technological representations. The actuating phase enabled students to actively engage in real-world problem-solving using STEM-based digital learning modules, which promoted higher-order numeracy processes. Finally, the controlling phase provided continuous feedback through digital assessments and reflective monitoring, allowing students to refine their quantitative reasoning. These structured instructional management processes explain how STEM-based digital learning modules systematically enhance numeracy rather than merely introducing technological novelty.

The analysis further indicates a positive association between improvements in physics learning management and students' numeracy gains. Classes that demonstrated higher POAC scores, particularly in the Planning and Actuating components, also showed higher N-gain values. This finding suggests that systematic instructional planning, effective classroom implementation, and continuous monitoring play a crucial role in supporting students' development of quantitative reasoning in physics learning (Johnson et al., 2020; Robbins & Coulter, 2018).

Learning Management and Numeracy Enhancement. The findings confirm that learning management optimizing is not merely a conceptual claim but an empirically observable process. Improvements in the planning and actuating stages facilitated more structured STEM-based learning experiences, which in turn supported students' numeracy development. These results are consistent with previous studies that emphasize the critical role of effective instructional management in enhancing higher-order learning outcomes.



The increase in students' literacy and numeracy skills scores refers to table 8 N-Gain.

Table 8. N-Gain Category

Variable	N-Gain	Category
Literacy	0.73	High
Numeracy	0.70	High

The results indicate that the implementation of the Physics Learning Management Handbook significantly improved students' literacy and numeracy skills. The high N-gain scores suggest that STEM-based learning activities successfully facilitated meaningful learning experiences through contextual problem-solving and interdisciplinary integration. These findings support previous studies demonstrating that STEM-based learning improves students' higher-order thinking, quantitative reasoning, and interdisciplinary problem-solving abilities (Kelley & Knowles, 2016; Li et al., 2020; Anggreiny et al., 2023). However, the novelty of this study lies in integrating STEM learning within a structured physics learning management framework emphasizing literacy and numeracy simultaneously.

B. Effect Size Analysis

Effect size analysis was conducted using Cohen's d formula.

$$d = \frac{M_2 - M_1}{SD_{pooled}}$$

The results are shown in Table 9.

Table 9. Effect Size Results

Variable	Cohen's d	Category
Literacy	0.86	Large Effect
Numeracy	0.82	Large Effect

The results indicate that the developed Physics Learning Management Handbook had a substantial effect on improving students' literacy and numeracy competencies. The large effect size suggests that the instructional intervention was educationally meaningful and not merely statistically significant. Compared with previous STEM learning studies emphasizing conceptual understanding and technology integration (Guzey et al., 2016; Li et al., 2020; Le et al., 2023), this study contributes novelty through the systematic integration of instructional management, literacy development, and numeracy enhancement within a physics learning management framework.

The findings indicate that the developed Physics Learning Management Handbook effectively supports literacy and numeracy enhancement through STEM-based physics learning. The integration of STEM principles enabled students to connect scientific concepts with mathematical reasoning and contextual problem-solving activities. From a literacy perspective, students demonstrated improvement in identifying scientific concepts, interpreting information, analyzing phenomena, and communicating scientific reasoning. This improvement occurred because STEM learning activities required students to actively observe, interpret, and explain physical phenomena scientifically.



From a numeracy perspective, students showed better performance in interpreting quantitative data, applying mathematical relationships, and solving contextual physics problems. The integration of mathematics into STEM-oriented physics activities encouraged students to develop quantitative reasoning skills beyond procedural formula application. The findings align with previous studies emphasizing that STEM learning promotes interdisciplinary thinking, scientific reasoning, and authentic problem-solving through contextual learning activities (English, 2017; Li et al., 2020; Winarti et al., 2021). Furthermore, the results are consistent with studies showing that contextual STEM instruction improves students' scientific reasoning and numeracy competencies (Kelley & Knowles, 2016; Li et al., 2020).

Nevertheless, this study offers several important novelties compared to prior research:

- 1) The development focused specifically on a Physics Learning Management Handbook rather than solely digital modules or STEM media;
- 2) Literacy and numeracy competencies were integrated simultaneously into STEM-based physics learning;
- 3) The instructional framework systematically combined learning management principles with STEM pedagogy;
- 4) The developed product emphasized instructional planning, implementation, and evaluation comprehensively.

The findings indicate that the developed STEM-based Physics Learning Management Handbook effectively supported students' literacy and numeracy development through contextual and interdisciplinary learning activities. The integration of science, technology, engineering, and mathematics encouraged students to analyze physical phenomena, interpret quantitative data, and apply mathematical reasoning in solving contextual physics problems. The structured learning management framework also facilitated systematic instructional implementation and meaningful learning experiences.

The implementation process also demonstrated that systematic learning management plays an important role in supporting STEM learning effectiveness. Through structured planning, organized activities, reflective evaluation, and continuous feedback, students became more engaged in meaningful learning experiences. In relation to Sustainable Development Goal 4 concerning quality education, STEM-based learning management contributes to more inclusive, contextual, and competency-oriented instructional practices that support students' literacy and numeracy development (UNESCO, 2022; OECD, 2023).

Implications of the Study

This study has several theoretical and practical implications.

Theoretical Implications

- 1) The study strengthens the theoretical relationship between STEM learning, literacy development, and numeracy enhancement in physics education.
- 2) The findings support the integration of instructional management principles within STEM-based learning frameworks.
- 3) The study contributes to the literature on interdisciplinary physics learning emphasizing contextual quantitative reasoning.



Practical Implications

- 1) The developed Physics Learning Management Handbook can serve as an instructional guide for teachers implementing STEM-based physics learning.
- 2) The book may assist educators in integrating literacy and numeracy competencies systematically into classroom instruction.
- 3) The instructional model may support the implementation of competency-based and student-centered learning in physics education.

Limitations of the Study

Several limitations should be acknowledged in this study.

- 1) The study was conducted only within one institutional context involving physics education students at Universitas Negeri Jakarta, limiting broader generalization.
- 2) The implementation focused primarily on Physics learning material, so further studies are needed for other topics (biology, chemistry, etc.).
- 3) The study emphasized literacy and numeracy competencies without extensively examining other higher-order skills such as creativity or collaboration.
- 4) The implementation period was relatively limited, making long-term impact analysis difficult.

Future studies are recommended to involve broader participant groups, longer implementation durations, and additional variables related to 21st-century competencies.

CONCLUSIONS

This study developed and evaluated a STEM-based Physics Learning Management Handbook using the ADDIE Research and Development model to support students' literacy and numeracy skills in physics learning. The developed product demonstrated high feasibility based on expert evaluations in terms of content quality, instructional design, media presentation, and learning suitability.

The implementation results showed that the developed learning resource effectively improved students' literacy and numeracy competencies. The N-gain analysis indicated high improvement categories for literacy and numeracy, while the effect size analysis demonstrated substantial educational impact on students' conceptual understanding, quantitative reasoning, and contextual problem-solving abilities.

The findings suggest that integrating STEM principles into physics learning management can facilitate meaningful interdisciplinary learning experiences by connecting scientific concepts, mathematical reasoning, technology utilization, and contextual applications. In addition to functioning as instructional material, the developed book also serves as a structured learning management guide that supports systematic planning, implementation, and evaluation processes in physics instruction.

The novelty of this study lies in the integration of literacy and numeracy competencies within a comprehensive STEM-based physics learning management framework. This study contributes to the development of competency-oriented physics education and supports the implementation of Sustainable Development Goal 4 concerning quality education.

Nevertheless, the study was limited to one educational context and focused on selected



physics learning materials. Future studies are recommended to involve broader participant groups, diverse physics topics, and longer implementation periods to further examine the applicability and effectiveness of STEM-based physics learning management in different educational settings.

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