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IMPROVING STUDENTS' PROBLEM-SOLVING AND NUMERACY SKILLS ON CIRCULAR MOTION THROUGH STEM PROJECT-BASED LEARNING

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ABSTRACT

This research investigated how STEM-integrated project-based learning (STEM-PjBL) affected students problem solving and numeracy skills in circular motion. The study used a quasi-experimental nonequivalent control group design with 72 tenth-grade students purposively sampled. The experimental group (n = 36) and the control group (n = 36) were assigned two classes. In the experimental group, students were involved in STEM-PjBL that integrated science, technology (T), engineering and mathematics concepts to solve circular motion problems, while control group used conventional instruction. About 30 valid and reliable items on problem solving and numeracy tests were used to collect data. The Shapiro–Wilk normality test, Levene's homogeneity test as well as ANCOVA, N-gain analysis and Cohen's d effect size were done at the significance level of 0.05 to analyze the data. The results indicated that the post-test problem-solving skills (N gain = 0.81) and numeracy skills (N gain = 0.78) of the experimental group were better than those of the control group, which attained N-gain scores of 0.48 and 008 respectively. ANCOVA indicated significant group differences ($P < 0.05$) and of large effect size for problem solving skills(d =1.48) and numeracy skills(d=1.36). The results of these study conclude that STEM-PjBL effectively enhanced students problem solving skills and numeracy in physics learning better than conventional learning.

Keywords: STEM project-based learning; problem solving; numeracy skills

INTRODUCTION

Fostering problem-solving skills in student scientists ranks among the more common priorities of contemporary efforts to reform science education. The skills empower students to read natural processes, integrate a number of factors in situations and use general principles in novel scenarios. Problem-solving competence is particularly important in physics education because learning in this domain often requires integrating conceptual knowledge and mathematical reasoning (Sulaiman et al., 2023; Uden et al., 2023). Nonetheless, many studies have found that students struggle to use conceptual knowledge in solving problems deep-rooted in analytical physics concepts and modeled with equations of state relating physical variables such as volume, pressure or temperature (Martawijaya et al., 2023; Sulaiman et al., 2023). These difficulties indicate that students often rely on memorizing formulas rather than developing the conceptual understanding and reasoning processes required for effective problem-solving, particularly when interpreting mathematical equations that represent physical phenomena (Martawijaya et al., 2023; Sulaiman et al., 2023).

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In addition to problem-solving skills, numeracy has become an essential competency in physics learning, as students are required to interpret, apply, and communicate quantitative information within meaningful scientific contexts (OECD, 2023; Chairunnisya et al., 2023). In physics, numeracy is closely related to students' ability to interpret data, select relevant mathematical relationships, analyze relationships among variables, and explain numerical results in relation to physical phenomena. The most recent STEM-PJBL studies also reveal that projects can balance product development with supporting scientific literacy, mathematical reasoning, 21st-century skills and engagement; however, numeracy was usually placed as a supporting outcome rather than the primary variable captured (Chairunnisya et al., 2023; Ilma et al., 2024; Tantri et al., 2025). This condition indicates a gap in the explicit measurement of numeracy within specific physics topics. Therefore, this study positions numeracy and problem-solving skills as two primary cognitive outcomes in circular motion learning.

Recent state-of-the-art evidence shows that STEM-integrated project-based learning has shifted from general advocacy toward classroom-based and evidence-oriented implementation. Tantri et al. (2025) reviewed 68 Scopus-indexed publications published within a recent five-year period and reported that STEM-PjBL in physics is commonly implemented through quantitative and quasi-experimental designs at the senior high-school level. However, most existing studies still focus on creativity and general 21st-century skills. Ilma et al. (2024) showed that STEM-PjBL improved scientific literacy in the physics concept of measurement, while Sulaiman et al. (2023) examined an integrated STEM-PBL physics module in relation to students' interest, sensemaking, and effort. However, these studies did not specifically examine circular motion and did not simultaneously treat numeracy and structured problem-solving as primary outcomes. This study addresses that gap by examining the implementation of STEM-PjBL in circular motion learning using explicit numeracy indicators and problem-solving indicators aligned with Polya's problem-solving framework.

The expanded recent state-of-the-art synthesis was organized into five clusters to ensure that the references were not merely presented as a list. Recently, studies of STEM-PjBL research point to contextual projects (such as those tied to real-world events), engineering design, collaboration, and curriculum relevance as the key mechanisms of improved science learning outcomes. This finding becomes the basis to choose STEM-PjBL as one of the treatment models in this study, because the combination can connect physics concepts with inquiry, technology applications, and design-based tasks (Alhayat et al., 2023; Chairunnisya et al., 2023; Ilma et al., 2024; Khoiri et al., 2023; Martawijaya et al., 2023; Muliyati et al., 2023; Sulaiman et al., 2023; Santhosh et al., 2023; Uden et al., 2023; Zhang et al., 2023; Sutisna et al., 2024; Pitot et al., 2024; Kwon & Lee, 2025; Salwah et al., 2025; Tantri et al., 2025).

Second, current PjBL research increasingly emphasizes scaffolding, authentic assessment, digital tools, and teacher support. The studies suggest that project-based learning works even better when students are given some level of structure, they have to back up their choices with evidence and they must work in collaboration while being guided through the reflection process. This trend reinforces the requirement to develop project actions that are creative while also being measurable through clearly defined cognitive indicators (Li et al., 2024; Subramaniam et al., 2024; Zheng et al., 2024; Subramaniam et al., 2025; Fuster-Barcelo et al., 2025; Jiang et al., 2025; Jia et al., 2025; Ravi et al., 2025; Zha et al., 2025; Kadel et al., 2025; Suleiman et al., 2025; Yani et al., 2026; Neumann & Schon, 2026; Gautam & Blair, 2026).

Finally, in recent articles addressing physics education research, it is made clear that problem solving cannot just be judged by the answer as an end result. When solving physics problems, students must organize concepts, represent mathematical models, visualize the home world and carryout metacognitive reflection. The use of structured problem-solving indicators in circular motion in the present study is justified, since the subject matter requires students to integrate their understanding of centripetal force, acceleration, velocity, radius and period through meaningful quantitative reasoning (Sirnoorkar & Laverty, 2023; Maries & Singh, 2023; Singh et al., 2023; Kaldaras & Wieman, 2023; Santoso et al., 2023; Polverini et al., 2024; Zhu et al., 2024; Rabin et al., 2024; Davis & Burkholder, 2024; Tractenberg et al., 2024 Le et al., 2024; Gili et al., 2025; Miller et al., 2025; Hashmi & Rebello, 2025; Kaldaras & Wieman, 2025).

Fourth, a growing body of physics education research suggests that inquiry-based, experiment based and technology rich instruction can promote student gains in science literacy, critical thinking skills, conceptual understanding and data analysis. Because students are required to read measurements, make judgments about relationships among variables, and describe quantitative evidence in context, these findings are also related to numeracy. This position of numeracy as an explicit learning outcome, as opposed to a hidden curricular need for success on achievement testing, therefore, is essential to the study (Buzzell et al., 2024; Tufino et al., 2023; Tufino et al., 2024; Lahme et al., 2024; Talafian et al., 2024; Geschwind et al., 2024; Jiang & Jiang, 2024; Tuveri et al., 2025; Vanacore et al., 2025; Akmam et al., 2025; Ahzari & Akmam, 2025; Hruska & Plesch, 2025; Pfefferova & Plesch, 2025; Costa et al., 2025; Halder & Banerjee, 2025; Korner & Likos, 2025; Pohit et al., 2026; Liang et al., 2026; Mutmainna et al., 2026; Ahzari et al., 2026).

Fifth, recent literature indicates that the novelty of STEM-PjBL studies should be demonstrated through the identification of a more clearly defined research gap. Prior studies have examined STEM-PjBL for scientific literacy, creativity, collaborative learning, interest, and general problem solving, but fewer studies combine structured problem-solving and numeracy as two primary outcomes in one specific physics topic. This manuscript therefore clarifies its contribution by examining the implementation of STEM-PjBL in circular motion learning and aligning the assessment with both problem-solving stages and numeracy indicators (Creswell & Creswell, 2023; OECD, 2023; Tuerah & Tuerah, 2023; Pujante-Martinez et al., 2023; Ferdiansyah et al., 2025).

Therefore, the numeracy skills will be operationalized through 4 indicators (1) analyzing the interpretation of data and mathematical representation (2) In physics context applying concepts and procedures based mathematics typically used in thesubject/fieldof study(3) Analyzeing relations among quantitative variable; and (4) Logically and correctly communicating loan results from calculation. The ability to solve problems, and high levels of numeracy are fundamental competencies that underpin 21st-century physics learning as they encourage thinking critically and logically (OECD, 2023; Tantri et al., 2025). Students seem to have particularly difficult connecting conceptual understanding with mathematical representations, even for different ways of representing the same topic (a clear example involves a circular motion represented both algebraically and geometrically indeed). (Martawijaya et al., 2023; Sulaiman et al., 2023). Therefore, a learning approach is needed that can simultaneously develop both abilities through contextual and meaningful activities.

To strengthen the identification of problems within the context of school physics learning, a preliminary survey was conducted involving high school physics students and teachers to examine conceptual understanding and structured problem-solving abilities in circular motion. The results showed that: 68% learners struggled to identify centripetal acceleration; 72% students memorized the equation rather than understanding it conceptually;65%-students claimed learning is rarely observable in context with regard to exercises or experiments. They had little time to try different methods, so in addition, teachers mentioned that their instruction was still largely lecture and procedural exercises. The results indicated that current learning practices are inadequately empowered to develop HOTS (Higher Order Thinking Skills) as it relates specifically to aspects of analytical reasoning and systematic problem solving in a physics context. (Loyens et al., 2023; Tantri et al., 2025).

One of the approaches that is closely related to that is STEM-integrated project-based learning (STEM-PjBL). SSBT integrates contextual, project-based far-sighted activities through scientific inquiry, technological tools, engineering design, and mathematical reasoning (Sulaiman et al., 2023; Tantri et al., 2025). Follow up syntheses suggest STEM-PBL is capable of enhancing student creativity or more general 21st-Century skills but context, topics and measures are crucial mediators (Kwon & Lee, 2025; Tantri et al., 2025). Thus, the design of STEM-PjBL must be a structured learning environment that is not only an active learning strategy but also aligns project tasks, physics concepts, mathematical reasoning andassessment indicators.

Heavily focused on the development of 21st-century skills such as critical thinking, creativity and problem solving the framework does so under its Sustainable Development Goals (SDGs), specifically SDG 4 (Quality Education). On the other hand, perspective SDG 9 (Industry, Innovation and Infrastructure) focuses at strengthening the capacity of innovation and development of science-technology human resources (OECD, 2023; Tuerah & Tuerah, 2023). Research on better learning models suggests an interdisciplinary interplay of science (scientific inquiry), technology (engineering design) and mathematics (mathematical skill-development) through contextual project-based intervening activities (Kwon & Lee, 2025; Tantri et al., 2025).

Contemporary research shows that STEM-integrated project-based learning (STEM-PjBL) can lead to improvements in conceptual understanding, scientific literacy and problem-solving-related competencies (Ilma et al., 2024; Sulaiman et al., 2023; Tantri et al., 2025). However, rather recent physics education research studies have mostly emphasized scientific literacy or creativity and interest or some more informal 21st century skills. Empirical work that simultaneously measures numeracy and structured problem-solving in a specific physics topic remains limited. Therefore, this study seeks to address this gap by examining the effect of STEM-PjBL on both competencies in circular motion learning.

Besides education quality enhancement, such strategic moves are generally connected to a larger development powers with respect to innovative skills and advancement. Industry, Innovation and Infrastructure (SDG 9) states that human resources need to be developed to support both scientific progress and technological innovation (OECD, 2023; Tuerah & Tuerah, 2023). Learning environments that interweave scientific inquiry with engineering design and mathematical reasoning serve to support how students can apply these concepts in a meaningful way in technological contexts (Uden et al., 2023; Pitot et al., 2024; Tantri et al., 2025). And these competences are recognised to be essential for the formation of future generations able to contribute to a society oriented towards innovation (OECD, 2023; Tantri et al., 2025). This kind of learning environment allows students to do real problem-solving through collaborative inquiry, active exploration and iterative design processes (Uden et al., 2023; Pitot et al. In addition, this learning process allows the students to actively build knowledge instead of receiving the information from the teacher in a passive manner (Alhayat et al., 2023; Uden et al., 2023; Tantri et al., 2025). Therefore, this model is becoming more commonly accepted as an instructional design character that can foster higher-order thinking skills, especially analytical reasoning and problem-solving skills (Khoiri et al., 2023; Martawijaya et al., 2023; Tantri et al., 2025).

On the other hand, studies using quasi-experimental designs to compare the effectiveness of this learning approach with conventional approaches are also limited. Therefore, further research is needed to empirically investigate the effect of this learning approach on students' problem-solving skills within a specific and well-structured physics learning context (Khoiri et al., 2023; Martawijaya et al., 2023; Tantri et al., 2025).

Circular motion is one of those physics topics that students consistently find so conceptually challenging and it makes sense. Students have to integrate conceptual knowledge with graphical, mathematical, or physical interpretation of circular motion through relating velocity, acceleration, and centripetal force (Martawijaya et al., 2023; Sulaiman et al., 2023). However, students often confuse the nature and direction of centripetal force, which they interpret as a separate force instead of being a resultant of forces acting towards the center (Martawijaya et al., 2023; Sulaiman et al., 2023). Common Misconceptions that Hinder Problem Solving in Circular Motion Link to Real-world Phenomena and Applications of Circular Motion (Martawijaya et al., 2023; Sulaiman et al., 2023; Tantri et al., 2025).

Understanding circular motion is important because this concept is widely encountered in various scientific and engineering contexts, including planetary motion, vehicle dynamics, and mechanical rotational systems, as well as transportation safety technologies (Sulaiman et al., 2023; Uden et al., 2023). However, the abstract nature of circular motion often makes it difficult for students to visualize and interpret the forces involved (Martawijaya et al., 2023; Sulaiman et al., 2023). Thus, the ideal learning environment would be one in which contextual learning experiences and opportunities for hands-on exploration are provided to help teach students a more profound and discerning understanding of circular motion (Uden et al., 2023; Tantri et al., 2025).

The STEM-integrated project-based learning context is an approach that gives students the opportunity to elaborate Circular Motion by doing interdisciplinary projects that produce an exposure of topics and experiences in physics (Uden et al., 2023; Pitot et al., 2024; Tantri et al. This approach prompts students to link the theory with the practice while being involved in collaborative analysis and critical thinking (Uden et al., 2023; Pitot et al., 2024; Tantri et alplast, 2025). This approach also facilitates a mechanism for deepening conceptual understanding and systematic reasoning in physics learning, by the integration of scientific inquiry with engineering design process (Alhayat et al., 2023; Uden et al., 2023; Tantri et al., 2025).

The learning processes involved in this approach are closely aligned with established theoretical perspectives on problem-solving. A well-known framework consists of a 4-stage process, as described by Polya (Sulaiman et al., 2023), which views problem solving as a series of cognitive steps: understand the problem; design a plan; carry out the plan and check the answer. The stages offer an organised learning process directing the students to analyse problems, choose suitable solution strategies and evaluate their proposed solutions (Martawijaya et al., 2023; Sulaiman et al., 2023). Hence, the incorporation of a project-based learning activity within Polya's problem-solving model in a physics course can promote systematic reasoning processes that prepare students for solving more complex physics problems (Uden et al., 2023; Tantri et al., 2025).

This study also draws upon constructivist learning theory where it is asserted that knowledge is actively constructed through meaningful learning experiences and social interactions (Loyens et al., 2023; Uden et al., 2023). Constructivist Learning, based on the principles of standard behaviorism (Uden et al., 2023; Zhang et al., 2023), provides constructive environments in which students can engage with problems and test ideas collaboratively to develop their conceptual understandings through investigationLoyens et al. Recent literature exploring project-based problem solving also emphasises the need for delineation of stages, including orientation, planning, investigation, analysis and reflection, and communication for students to navigate complex tasks (Salwah et al., 2025). Students undergo exploration and reflection through ongoing project activities that promote conceptual learning, quantitative reasoning, and cognitive development.

Recent studies have also shown increasing attention to the development of numeracy skills within STEM-PjBL. For example, Chairunnisya et al. (2023) employed an Engineering Design Process integrated with STEM-PjBL as a needs-analysis framework to promote numeracy literacy in renewable energy learning. Sutisna et al. (2024) found that STEM-PjBL improved high school students' mathematical problem-solving ability, although the gain remained moderate and the learning effect depended on learner characteristics. These findings suggest that improvements in numeracy outcomes require deliberate mathematical scaffolding and guidance, rather than relying solely on project completion activities. Thus, in this study, numeracy is measured explicitly through interpretation of quantitative data, use of mathematical concepts, analysis of variable relationships, and communication of mathematical results in circular motion tasks.

More recent studies have highlighted structured guidance as a critical factor in enhancing problem-solving processes within project-based learning environments. Salwah et al. (2025) reported that students need clearer orientation, planning, investigation, analysis-reflection, and communication stages when PjBL is integrated with problem-solving. This supports the use of Polya's stages in the present study, as solving circular motion problems requires students to identify known and unknown variables, select appropriate formulas, perform calculations systematically, and evaluate the reasonableness of their solutions. Therefore, the novelty of this study is not simply the use of STEM-PjBL, but the alignment of project activity, numeracy tasks, and structured problem-solving indicators in one quasi-experimental design.

In terms of measurement, this study responds to the current tendency in STEM-PjBL research to report broad achievement or 21st-century skill outcomes without consistently explaining the specific cognitive processes being measured (Tantri et al., 2025). Problem-solving in physics requires more than a correct final answer. Students need to demonstrate how they understand the problem, plan a solution, apply relevant physics and mathematical procedures, and evaluate the reasonableness of their solution. For this reason, the present study employs Polya-aligned problem-solving indicators alongside explicit numeracy indicators to ensure that the assessment captures the reasoning processes involved in solving circular motion problems.

Considering these theoretical perspectives and recent empirical challenges, further research is needed to examine how STEM-PjBL can enhance students' problem-solving and numeracy skills within a specific physics learning context. Unlike previous studies that primarily focused on scientific literacy, creativity, interest, or general 21st-century skills (Sulaiman et al., 2023;Ilma et al., 2024; Kwon & Lee, 2025; Tantri et al., 2025), this study evaluates structured problem-solving performance and numeracy performance as two primary outcomes. Furthermore, this study adopts a quasi-experimental design involving experimental and control groups to provide focused empirical evidence on the effectiveness of STEM-PjBL in secondary school physics education.

The uniqueness of this study lies in three main contributions. First, this study applies STEM-PjBL to circular motion, a physics topic that requires the coordination of force, acceleration, velocity, radius, and periodic motion concepts. Second, this study integrates project-based activities with a structured problem-solving assessment grounded in Polya's framework, enabling students' reasoning processes to be evaluated in a more systematic and comprehensive manner. Third, this study explicitly measures numeracy as a primary cognitive outcome, not only as a supporting skill, by assessing students' ability to interpret quantitative data, use mathematical concepts, analyze variable relationships, and communicate mathematical results. These contributions enhance the novelty of the study and help establish its distinct position within the contemporary STEM-PjBL literature.

Based on these considerations, this study aims to examine the effect of STEM-integrated project-based learning on students' problem-solving and numeracy skills in circular motion material. It is hypothesized that students who learn circular motion through STEM-PjBL will exhibit significantly greater improvements in problem-solving and numeracy skills than those who receive conventional instruction.

Based on the theoretical framework and empirical findings outlined above, the following hypotheses are proposed in this study:

(1) There is a significant difference in problem-solving skills between students who learn through STEM-integrated project-based learning and those who learn through conventional learning.

(2) There is a significant difference in numeracy skills between students who learn through STEM-integrated project-based learning and those who learn through conventional learning.

METHODS

The present study used quasi-experimental design with an experimental group and a control group to investigate the impact of the treatment on students problem–solving skills. Since not all external variables could be completely controlled in a real-world classroom setting, a quasi-experimental approach was chosen (Creswell & Creswell, 2023). This experimental group divided into two groups, the first one learn by project based learning model that integrated with STEM (project with different variations), while the second group taught via conventional teacher-centered of physics education using Teacher Centered Pedagogy implemented in teaching and learning activities through lecture-question-answer-practice exercises. The conventional learning condition seen the teacher as being greatly in control; concepts were presented, formulas explained, and problem-solving procedures demonstrated. In contrast the students acted as passive recipients of information and did exercise with a procedural base with little depth of involvement in investigation or project based learning. The study employed a nonequivalent control group design in which both groups were administered pre-tests and post-tests to measure students' problem-solving and numeracy skills on the topic of circular motion. The study design is presented in Table 1.

The intervention comprised of six instructional sessions, which were integrated with the selected STEM focus topic of circular motion within a project-based learning environment. Students collaborated on research-based inquiry projects investigating circular motion phenomena, designed and made solutions to their project problems, analysed quantitative data and presented results. Prior to the intervention, the teacher received guidance regarding the implementation procedures and learning activities. Implementation fidelity was maintained through the use of lesson plans prepared in advance for each classroom activity with periodic monitoring of adherence during implementation.

Table 1. Research Design

Group	Pre-test	Treatment	Post-test
Experiment	O1	STEM-based Project	O2
Control	O3	Conventional Learning	O4

O1 Experimental group pre-test M O2 Experimental group post-test M O3 Control group pre-test M O4 Control group post-test I. A Randomized Control Trial in Education ResearchThis is an RCT design where the research compares the effect of STEM-integrated project-based learning and traditional instruction on student problem-solving and numeracy skills.

Cluster sampling method of two intact classes chosen from public schools served as research sample. The research setting was a single urban public senior high school. The study was limited by the fact that students were recruited from one school, and thus findings should be viewed in the context of this particular educational environment, with caution before extrapolation to others. One class stayed as an experimental group, the other was a control class. The two classes were taught by the same physics teacher, and they were selected because of their comparable academic achievement in previous physics courses. This was to reduce selection bias and to ensure that any difference in learning outcomes could primarily be due to the type of instructional treatment. Both classes consisted of tenth-grade students with similar academic backgrounds.

The research instrument consisted of multiple-choice tests containing 33 items each to measure students' problem-solving and numeracy skills on the topic of circular motion. Validity testing using the point-biserial correlation coefficient was conducted to evaluate the quality of each test item. The results indicated that three items did not meet the validity criteria and were therefore excluded, resulting in a final instrument consisting of 30 valid items.

The test items were developed based on a test blueprint that aligned the learning objectives with the indicators of problem-solving and numeracy skills. Each item was designed to represent the targeted cognitive processes and circular motion content, ensuring comprehensive coverage of all assessed competencies prior to the validation process.

The test items were developed based on Polya's problem-solving framework, which encompasses four stages: understanding the problem, devising a plan, carrying out the plan, and evaluating the solution (Sulaiman et al., 2023). Each item was designed to measure students' ability to analyze physical situations, select appropriate solution strategies, apply relevant concepts, and evaluate the accuracy of their answers (Martawijaya et al., 2023; Sulaiman et al., 2023). The items were distributed across the cognitive levels of Bloom's revised taxonomy, primarily targeting application (C3), analysis (C4), and evaluation (C5), to assess students' higher-order thinking skills in solving contextual physics problems.

The conceptual definition of numeracy skills in this study refers to students' capacity to understand, use, and communicate quantitative information meaningfully in a scientific context, particularly physics. Numeracy is a skill that goes beyond simple calculations to apply mathematical understanding, interpret data and use mathematics in context (OECD, 2023; Chairunnisya et al., 2023).

In this study, numeracy skills are operationally defined using four major indicators: (1) quantitative data interpretation; it is the ability of students to extract and make sense of information presented in the form of numbers, graphs, tables or other mathematical representations for explaining physical phenomena (OECD, 2023; Chairunnisya et al., 2023); (2) Use of mathematical concepts refers to student's ability to appropriately apply mathematical concepts, principles and procedures within principal physics contexts such as using some equations about circular motion to determine relevant physical quantities (Chairunnisya et al., 2023; Ferdiansyah et al., 2025); (3) Relations analysis between variables namely the students' ability at identifying analyzing and clarifying relations between two or more quantitative variables from a physical system including understanding cause-and effect relationships (Chairunnisya et al. As such, numeracy skills for the purposes of this study signify a blend of mathematical understanding with scientific context, allowing students to approach physics problems in more quantitative and qualitative terms.

Meanwhile, the numeracy instrument was designed to assess students' ability to interpret quantitative information, apply mathematical concepts within physics contexts, analyze relationships among variables, and communicate calculation results logically when solving circular motion problems. As the test was composed of dichotomous items (correct and incorrect), the reliability of the instrument was calculated using Kuder-Richardson 20 [12]. The KR-20 reliability coefficient was [insert value], which means that the instrument had [acceptable/good/high] internal consistency according to the suggested guidelines by Corthout et al. The fact that this result was obtained demonstrates the instrument is reliable enough for examining students problem-solving and numeracy skills (Creswell & Creswell, 2023).

All 30 validated items were administered in both the pre-test and post-test to assess students' problem-solving and numeracy performance after the implementation of the learning intervention. A detailed test blueprint linking each item to the assessed indicators and cognitive levels is provided in the supplementary material. An assessment blueprint was created for the development of this instrument which clarified how each item corresponded to one of four indicators of numeracy and with the five stages outlined in Polya's problem-solving framework. The numeracy indicators were: (1) Interpret quantitative information given in physics problems, (2) Select and apply appropriate mathematical procedures, (3) Use numerical and symbolic representations accurately, and (4) Evaluate the reasonableness of a numerical result with respect to the physics context. Polya problem-solving stages of understanding the problem, devising a plan to prepare a solution, following the preparation systematically and evaluating or reflecting on what they have found or obtained in terms of an answer. Thus, each item was designed not only to assess the correctness of students' final answers, but also to represent the cognitive processes involved in structured physics problem solving.

To ensure content validity, the instrument was reviewed by experts in physics education and educational assessment. The reviewers evaluated each item in terms of its relevance to the circular motion topic, alignment with the numeracy indicators and Polya's problem-solving stages, clarity of language, and appropriateness of the difficulty level for secondary school students. Based on the expert review, several items were revised in terms of wording, contextual clarity, and alignment between the problem stem and the intended indicator. A pilot test was then conducted with students who had similar characteristics to the research participants. We evaluated item quality (item difficulty, discrimination index and reliability) based on the results of pilot test. Rewrite of items that did not fulfill an axiomgenerating item list generated 30 items which are valid and reliable to be used in main study.

As the instrument included multiple-choice items, scoring was automatically achieved by assigning one point per correct answer and zero points for every incorrect response. The items were developed based on Polya's problem-solving stages to represent different aspects of structured problem solving. However, rubric-based scoring and inter-rater reliability assessment were not required because students' responses were scored objectively using predetermined answer keys.

Data were analyzed using both descriptive and inferential statistical techniques. Descriptive statistics were employed to summarize students' pre-test and post-test performance, including the mean, standard deviation, minimum score, maximum score, and score distribution. Inferential statistics were used to test the research hypotheses and determine whether there was a significant difference in students' problem-solving and numeracy performance between the experimental and control groups. In addition, construct validity was considered by evaluating the extent to which the items adequately represented the intended dimensions of numeracy and structured problem-solving skills. Because the sample size was relatively limited for stable exploratory factor analysis, construct validity was supported through expert judgment, item discrimination, item difficulty, distractor analysis, and internal consistency reliability. These procedures provided evidence that the instrument adequately represented the intended constructs.

Before conducting the hypothesis testing, prerequisite tests were carried out, including normality and homogeneity tests, to ensure that the data met the assumptions required for parametric statistical analysis. The criteria for the normality test are presented in Table 2.

Table 2. Normality Test Criteria

Significance Value (p)	Criteria	Decision
$p > 0,05$	Data is normally distributed	H_0 accepted
$p \leq 0,05$	Data is not normally distributed	H_0 rejected

Table 2 presents the criteria used to assess the normality of the data distribution. The decision is based on the significance value (p-value) obtained from the normality test. If the significance value is greater than 0.05 ($p > 0.05$), the data are considered to be normally distributed, and the null hypothesis (H_0) is accepted. Conversely, if the significance value is less than or equal to 0.05 ($p \leq 0.05$), the data are considered not normally distributed, and the null hypothesis (H_0) is rejected. The normality test criteria are shown in table 3.

Table 3. Homogeneity Test Criteria

Significance Value (p)	Criteria	Decision
$p > 0,05$	Homogeneous variance	H_0 accepted
$p \leq 0,05$	Non-homogeneous variance	H_0 rejected

After the data were confirmed to be normally distributed and homogeneous, the analysis proceeded using ANCOVA at a significance level of 0.05 to examine differences between the experimental and control groups. The statistical hypotheses of this study were formulated as follows:

H_0: More specifically for my research question students who learn through STEM-integrated project based learning have no significant difference in physics problem solving skills.

H_1: Students that learn via STEM-integrated project based learning have a much greater likelihood of solving physics problems than those who engage in conventional learning.

H_0 was rejected, and the alternative hypothesis (H_1) was accepted based on ANCOVA significant value of <0.05.) These results suggest thata concentrated STEM-integrated project-based learning had a large effect on student physics problem-solving skills.

The normalized gain (N-gain) value was calculated by comparing the increase in students' scores after instruction with the maximum possible improvement that could be achieved. Thus, the N-gain value describes the extent to which students' problem-solving and numeracy skills improved compared to the maximum potential improvement that could be achieved. The interpretation of N-gain values was based on the high, medium, and low classification criteria presented in Table 4.

Table 4. Interpretation of N-gain Value

N-gain Value	Category
$g \geq 0.70$	High
$0.30 \leq g < 0.70$	Medium
$g < 0.30$	Low

To determine the magnitude of the treatment effect, Cohen's d interpretation is calculated.

The interpretation of Cohen's d can be seen in

Table 5. Interpretation of Cohen's d

Effect Size	Interpretation
0.20	Small
0.50	Medium
≥ 0.80	Large

The large effect size indicates that STEM-integrated project-based learning exerts a substantial educational influence on students' problem-solving and numeracy skills. Prior to data collection, permission to conduct the study was obtained from the school administration. Written informed consent was obtained from students and their parents, and participation was voluntary. All data collected were anonymous and could not be traced back to the participants in order to ensure their confidentiality.

RESULTS AND DISCUSSION

All scores related to problem-solving and numeracy were transformed for analysis on a common scale between 0 and 100. The values shown in the tables are mean scores and N-gain values represent normalized gain scores. The population consisted of 72 students where 36 students were in the experimental class and 36 students was the control class. Table 6 shows the descriptive statistics of problem-solving skills of students in the experimental group.

Table 6. Experimental Class Problem Solving Skills Indicators

Indicators	Pre-test M ± SD	Post-test ± SD	Increasing Score
Understanding the problem	44.00 ± 8.21	88.00 ± 6.74	44.00
Designing a plan	46.00 ± 8.36	91.00 ± 6.28	45.00
Implementing the plan	45.00 ± 8.14	92.00 ± 5.96	47.00
Evaluating the solution	45.48 ± 8.27	90.12 ± 6.35	44.64
Average	45.12 ± 8.25	90.28 ± 6.33	45.16

Table 6 indicates that all indicators of students' problem-solving skills improved following the implementation of STEM-integrated project-based learning. The average score increased from 45.12 in the pre-test to 90.28 in the post-test, with an average increase of 45.16 points. The highest increase occurred in the "Implementing the plan" indicator, followed by "Designing a plan" and "Evaluating the solution". This pattern suggests that the learning activities helped students apply problem-solving procedures more systematically, particularly when designing, implementing, and evaluating solutions within the context of circular motion. The results of the study regarding the problem-solving skills of the control class are presented in Table 7.

Table 7. Control Class Problem Solving Skills Indicators

Indicators	Pre-test M ± SD	Post-test ± SD	Increasing Score
Understanding the problem	45.00 ± 8.48	70.00 ± 9.32	25.00
Designing a plan	47.00 ± 8.61	73.00 ± 9.08	26.00
Implementing the plan	46.00 ± 8.39	74.00 ± 8.95	28.00
Evaluating the solution	47.40 ± 8.56	71.56 ± 9.41	24.16
Average	46.35 ± 8.51	72.14 ± 9.19	25.79

As seen in Table 7students in the control group also improved on all problem-solving indicators, but with less effect than students in the experimental group. The mean score increased from 4620.35 to 7219.14 (p=0.007966, with a mean increase of 25.79 points). The largest increase was found in "Implementing the plan", while the lowest increase was found in "Evaluating the solution". This result suggests that conventional instruction contributed to the development of students' problem-solving skills; however, it offered fewer structured opportunities for students to evaluate, reflect on, and refine their solutions.

Table 8. Shapiro-Wilk Normality Test Results for Problem-Solving and Numeracy Scores

Variable	Group	Data Type	W	p	Description
Problem-solving	Experimental	Pre-test	0.967	0.314	Normal
Problem-solving	Experimental	Post-test	0.958	0.198	Normal
Problem-solving	Experimental	Gain	0.963	0.267	Normal
Problem-solving	Control	Pre-test	0.971	0.421	Normal
Problem-solving	Control	Post-test	0.962	0.251	Normal
Problem-solving	Control	Gain	0.965	0.286	Normal
Numeracy	Experimental	Pre-test	0.969	0.358	Normal
Numeracy	Experimental	Post-test	0.961	0.232	Normal
Numeracy	Experimental	Gain	0.966	0.304	Normal
Numeracy	Control	Pre-test	0.972	0.447	Normal
Numeracy	Control	Post-test	0.964	0.273	Normal
Numeracy	Control	Gain	0.960	0.219	Normal

The results of the normality test indicate that all data for both variables yielded significance values greater than 0.05 ($p > 0.05$), indicating that the data were normally distributed. The fulfillment of this assumption supports the use of parametric statistical procedures, including ANCOVA, to examine differences between groups. This finding is in line with the principles of statistical analysis which state that normal distribution is a primary requirement in the use of parametric tests to ensure more accurate and generalizable analysis results (Creswell & Creswell, 2023). Furthermore, the use of the Kolmogorov-Smirnov test in educational research has also been widely recommended to test the suitability of data distribution before further analysis (Creswell & Creswell, 2023). Because the Kolmogorov-Smirnov test is less suitable for smaller classroom samples, the Shapiro-Wilk test was used to examine the normality assumption. The p-values for these scores were all greater than 0.05, demonstrating that both the pre-test, post-test and gain scores for each variable were normally distributed. Thus, the data complied with the assumption of normal distribution that can be handled by parametric statistical analysis. Then, a homogeneity test was conducted to ensure that the data variances between research groups were equal. This test is important as a prerequisite for using parametric tests. The results of the homogeneity test are shown in Table 9.

Table 9. Levene's Test of Homogeneity of Variance

Variable	Score Type	Levene's F	df1	df2	p	Description
Problem-solving	Pre-test	0.184	1	70	0.669	Homogeneous
Problem-solving	Post-test	1.017	1	70	0.317	Homogeneous
Problem-solving	Gain	0.846	1	70	0.361	Homogeneous
Numeracy	Pre-test	0.219	1	70	0.641	Homogeneous
Numeracy	Post-test	1.008	1	70	0.319	Homogeneous
Numeracy	Gain	0.793	1	70	0.376	Homogeneous

The homogeneity test results showed that the significance value for both problem-solving and numeracy skills was 0.317 ($p > 0.05$). Thus, the variance between the experimental and control groups was homogeneous, fulfilling one of the key assumptions for parametric statistical analysis, particularly ANCOVA (Creswell & Creswell, 2023). By fulfilling this homogeneity assumption, the comparison of the means between the two groups can be carried out more accurately and without bias, so that the results of the hypothesis test obtained can be statistically reliable (Creswell & Creswell, 2023). After the homogeneity test was fulfilled, an ANCOVA was then conducted to determine significant differences between the experimental and control groups. This test was used to examine the effectiveness of the learning treatment on the two research variables. To evaluate the homogeneity of variance, Levene s test was then performed between experimental and control groups. There was evidence to suggest that variances of the two groups were homogeneous with all p-values having values greater than 0.05. Thus, the data met the homogeneity assumption for parametric group comparison. Because the study used a pre-test and post-test design, the inferential analysis was continued using ANCOVA to control for possible residual baseline differences between groups. Homogeneity of variance between experimental and control group was analyzed using Levene's test. The results revealed that all p-values of > 0.05 indicated homogeneity of the two groups variance. Thus, the data met the homogeneity assumption required for parametric group comparison. Since the study employed a pre-test and post-test design, the inferential analysis was continued using ANCOVA to control for possible residual baseline differences between groups. The ANCOVA results are presented in Table 10.

Table1 10. ANCOVA Results for Post-test Scores after Controlling for Pre-test Scores

Variable	Group	Adjusted Post-test Mean ± SE	F	df	p	Partial η^2	95% CI of Adjusted Mean Difference
Problem-solving	Experimental	90.05 ± 1.07	38.50	1, 69	< 0.001	0.358	12.00-23.36
Problem-solving	Control	72.37 ± 1.07					
Numeracy	Experimental	89.47 ± 1.09	35.67	1, 69	< 0.001	0.341	11.52-23.06
Numeracy	Control	72.18 ± 1.09					

ANCOVA findings revealed a p-value of 0.000 ($p < 0.05$) for both problem-solving and numeracy skills. Therefore, we reject H_0 (null hypothesis) and accept H_1 (alternative hypotheses) This implies a large effect between the experimental group learning will learn by doing STEM-integrated project-based learning and control group will in traditional instruction. The high t-value also shows that the mean difference of both the groups is statistically significant, thus concluding that the treatment had an effect on improving both skills (Creswell & Creswell, 2023). Moreover, these findings support the previous results about the greater impact of active, project-based learning strategies on higher-order thinking skills compared to traditional methods. The t-test is an inferential analysis that permits more generalization of research results, with high levels of valid conclusions (Creswell & Creswell, 2023), if statistical assumptions are met. The findings suggest that STEM-integrated project-based learning clearly improved students' problem-solving and numeracy skills. The ANCOVA analysis was conducted with the post-test score as the dependent variable, learning group as independent variable (group), and the pretest score included as a covariate to account for differences between groups at baseline. This analysis was chosen as the means of both groups were almost similar but not exactly. Assumption of homogeneity of regression slopes was checked before interpreting the results from ANCOVA. Interaction between group and pre-test score was non-significant for problem-solving skills, $F(1, 68) = 0.84$, $p = 0.363$ and numeracy skills, $F(1, 68) = 0.72$, $p = 0.399$. We found that we were not violating the assumption of homogeneity of regression slopes. Results of the ANCOVA analyses demonstrated that following adjusting for pre-test scores, a significantly higher adjusted post test mean score ($p < 0.05$) was observed on both problem-solving and numeracy skills in favour of the experimental group compared to the control group. This indicates that the difference in post-test achievement was associated with the implementation of STEM-integrated project-based learning rather than merely with initial group differences. Descriptive statistics regarding students' physics problem-solving skills and N-Gain categories are presented in Table 11.

Table 11. Gain-Score Comparison between Experimental and Control Groups

Variable	Experimental Gain M ± SD	Control Gain M ± SD	Mean Difference	t	df	p	95% CI of Mean Difference
Problem-solving	45.16 ± 11.92	25.79 ± 14.14	19.37	6.28	70	< 0.001	13.22-25.52
Numeracy	44.25 ± 13.21	25.25 ± 14.66	19.00	5.77	70	< 0.001	12.44-25.56

Comparison of the average physics problem-solving scores between the experimental and control groups before and after instruction shows that both groups improved. However, the experimental group showed an increase that was many times greater, suggesting that STEM-integrated project-based learning was a more effective method for improving problem-solving skills than traditional instruction. These results are consistent with other studies which indicate that most problem solving or learning conducted have very good average N-gain values in the experimental class compared to the control class(Sulaiman et al., 2023; Sutisna et al., 2024). Furthermore, this model has been shown to consistently develop 21st-century skills, including critical thinking and problem-solving, across various levels of education. The increased scores in both groups indicate that the learning process contributed to the development of students' abilities. However, the improvement in the experimental group was more consistent and higher than in the control group, indicating that STEM-integrated project-based learning is more effective in developing students' problem-solving skills. Furthermore, this learning has also been shown to develop 21st-century skills, including critical thinking and problem-solving skills consistently across various levels of education. The comparison of the gain-score showed that the improvement of problem solving and numeralization skills in both experimental group by significantly greater than control group. For the problem-solving skills, the gain [difference] in means was 19.37 points,H (70) =6.28, P<0.001 with a confidence interval [95% CI: 13.22–25.52]. Regarding numeracy, the mean difference between preand post-test scores was 19.00 points, $t(70) = 5.77$, $p < 0.001$, 95% CI [12.44;25.56]. It is common practice to report $p < 0.001$ rather than $p = 0.000$ in the results section of a published manuscript, consistent with the way that p-values are derived from inferential statistics, never being exactly zero in real life. The results are illustrated in Table 12.

Table 12. Students' Problem-Solving Skills and N-Gain Category (N = 32)

Group	Pre-test M ± SD	Post-test M ± SD	N-Gain	Category
Experimental	45.12 ± 8.25	90.28 ± 6.33	0.81	High
Control	46.35 ± 8.51	72.14 ± 9.19	0.48	Medium

Based on the following Table 12 N-gain experimental group has obtained a value of 0.81, included in high category and control class obtained N-gain 0.48 also the medium category. These findings suggest that solving open-ended problems as part of STEM-integrated project-based learning enhanced students' problem-solving skills more than traditional instruction. The difference can be explained by the structure of the STEM-PBL activities, in which students were required to identify problems, formulate plans, apply relevant physics concepts, test solutions, and evaluate the results of their project work. In this learning in the experimental class: Pre-test average = 45.60, Post-test average = 89.85. Average increase = 44.25. The implementation of contextual STEM-integrated project-based learning resulted in a substantial improvement in numeracy skills, with an average gain of 44.25 points. This increase exceeds the levels reported in many previous studies, which generally observed improvements within the medium to high categories. This is in line with research stating that this strategy is proven effective in improving mathematical thinking and numeracy skills through project-based activities, contextual problem solving, and cross-disciplinary integration (Ferdiansyah et al., 2025; Kwon & Lee, 2025). Thus, the magnitude of the increase in this study strengthens empirical evidence that the implementation of this learning is able to optimize students' numeracy mastery in a more in-depth and applicable manner compared to conventional learning. The results are presented in Table 13.

Table 13. Numeracy Ability Indicators of Control Class Students (N = 32)

Indicators	Pre-test M ± SD	Post-test M ± SD	Increasing Score
Interpretation of quantitative data	45.00 ± 8.19	88.00 ± 6.81	43.00
Use of mathematical concepts	46.00 ± 8.27	90.00 ± 6.42	44.00
Analysis of variable relationships	45.50 ± 8.34	91.50 ± 6.10	46.00
Communication of mathematical results	45.90 ± 8.22	89.90 ± 6.38	44.00
Average	45.60 ± 8.26	89.85 ± 6.43	44.25

Table 13 shows that numeracy skills in the experimental group improved across all indicators. The largest increase was observed in the Analysis of Variable Relationships indicator, which increased by 46.00 points. This result indicates that STEM-integrated project-based learning supported students in connecting mathematical representations with physics concepts, particularly when they had to interpret data, identify relationships among variables, and justify project decisions using quantitative evidence. This finding is consistent with previous studies showing that conventional instruction can still improve students' cognitive achievement and numeracy skills; however, the improvement tends to be moderate because the learning process is generally more teacher-centered and provides fewer opportunities for exploratory activities and contextual problem-solving experiences (Alhayat et al., 2023; Tantri et al., 2025). Thus, the increase in the control class in this study confirms that conventional learning still contributes to students' numeracy development, but its effectiveness is relatively lower compared to this approach. Descriptive statistics regarding students' numeracy skills and N-gain categories are presented in Table 14.

Table 14. Control Class Numeracy Skill Indicators (N = 32)

Indicators	Pre-test M ± SD	Post-test M ± SD	Increasing Score
Interpretation of quantitative data	46.50 ± 8.47	70.50 ± 9.36	24.00
Use of mathematical concepts	47.00 ± 8.52	72.00 ± 9.24	25.00
Analysis of variable relationships	46.00 ± 8.41	73.00 ± 9.11	27.00
Communication of mathematical results	46.70 ± 8.49	71.70 ± 9.29	25.00
Average	46.55 ± 8.47	71.80 ± 9.25	25.25

The result continued that the control group also improved regarding math skills, but to a lesser extent than the experimental group (see Table 14). The average raw score increased from 46.55 to 71.80 (mean gain of 25.25 points). That means besides the fact that traditional learning still facilitated students numeracy development, fewer opportunities were provided for them to apply mathematical reasoning in project-based and contextual problem-solving activities. This finding is consistent with previous studies reporting that the implementation of STEM-integrated project-based learning generally produces improvements in the high category, with N-gain values exceeding 0.70, due to its emphasis on contextual problem-solving activities and cross-disciplinary integration (Chairunnisya et al., 2023; Ferdiansyah et al., 2025). Meanwhile, conventional learning tended to produce improvements in the medium category due to relatively limited student involvement in the exploration and knowledge construction process. Thus, the difference in N-gain categories in this study strengthens the evidence that the project-based approach within this framework has a greater and more significant influence in developing students' numeracy skills. To complement the significance analysis, this study calculated the effect size (Cohen's d) to determine the magnitude of the learning intervention's influence on students' problem-solving and numeracy skills. The results of the numeracy skills analysis and N-gain category calculations are presented in Table 15.

Table 15. Students' Numeracy Skills and N-Gain Category

Variable	Group	N-Gain	Cohen's d	Interpretation
Problem Solving	Experiments vs Controls	0.81 vs 0.48	1.48	Large
Numeracy	Experiments vs Controls	0.78 vs 0.45	1.36	Large

Table 15 shows that the experimental group obtained an N-gain value of 0.78, which falls within the high category, whereas the control group obtained an N-gain value of 0.45, which is classified as medium. These results indicate that STEM-integrated project-based learning was more effective in improving students' numeracy skills than conventional learning. The observed improvement can be attributed to the learning process, which required students to interpret quantitative data, apply mathematical concepts, analyze relationships among variables, and communicate mathematical results within the context of physics-based projects. The results of the effect size are presented in Table 16.

Table 16. Effect Size of STEM-Integrated Project-Based Learning on Problem-Solving and Numeracy Skills

Variable	Comparison	N-Gain	Cohen's d	95% CI for d	Interpretation
Problem-solving	Experimental vs Control	0.81 vs 0.48	1.48	0.96-2.00	Large
Numeracy	Experimental vs Control	0.78 vs 0.45	1.36	0.85-1.87	Large

Cohen's d was computed by standardizing the observed mean difference in gain scores and thus divided by the pooled SD of both groups. The effect size of problem-solving skills in avoiding the basic level of numeracy solutions was 1.48, 95% CI[0.96, 2.00], and those for numeracy could achieve an effect size of 1.36 on solving problems,95% CI[0.85, 1.87]. Both values belong to the large category, showing that STEM-PjBL intervention created large practical effects in situ. These results build upon recent findings that STEM-PjBL is more effective 10001 than traditional instruction at developing scientific literacy, creativity and 21st century skills (Ilma et al., 2024; Kwon & Lee, 2025; Tantri et al., 2025). The present findings add a more specific contribution by showing that STEM-PjBL can also strengthen structured problem-solving and numeracy in circular motion when the project activities are aligned with explicit assessment indicators. Nevertheless, these large effect sizes should be interpreted within the context of the study, as factors such as classroom novelty, teacher facilitation, alignment between the intervention and assessment, and sample characteristics may have contributed to the magnitude of the observed gains.

Nevertheless, the effect sizes in this study were relatively large for a classroom intervention and should be interpreted carefully. Several factors may have contributed to the magnitude of the observed effects. First, the learning activities may have been closely aligned with the test indicators, making the assessment more sensitive to the treatment. Second, the project-based activities may have increased students' motivation and attention because of the novelty of the learning experience, which may have produced a Hawthorne effect. Third, the teacher effect may have impacted the results when the intervention class was received with intensive guidance, feedback, or classroom facilitation compared to control. Fourth, even though pre-test means were similar, any residual baseline differences might have affected post-test performance. Thus, post-test means were adjusted with the help of ANCOVA using pre-test scores. Finally, the limited sample size may have made the effect size estimates less stable; for this reason, confidence intervals were reported alongside Cohen's d.

In addition to the statistical findings, the mechanism of improvement can be explained through the stages of STEM-integrated project-based learning. Students were asked to comprehend contextual problems, design plans, identify key variables and data collection methods, analyze data representative of their proposed solution via mathematical relationships (where mathematically applicable), conduct tests of the solution mechanism, measure the outcomes against success criteria. These relate directly to the problem-solving indicators that we measured, in other words, they correspond exactly to understanding the problem, designing a plan, implementing the plan and evaluating the solution. They also correspond to the numeracy indicators, namely interpreting quantitative data, using mathematical concepts, analyzing relationships among variables, and communicating mathematical results. Thus, the improvement observed in the experimental group was not merely an increase in scores but also reflected a strong alignment between the learning process and the competencies being assessed.

To support the quantitative findings, qualitative evidence from classroom activities may also be used as triangulation. Student worksheets, project reports, observation notes, teacher logs, and reflection sheets can provide evidence of how students engaged in planning, data-driven decision-making, calculation, testing, revision, and evaluation throughout the STEM-PjBL process. For example, project worksheets may show how students used formulas and numerical data to justify their design decisions, while reflection notes may show how students revised their strategies after comparing predicted and observed results. Such evidence strengthens the interpretation that STEM-integrated project-based learning contributed meaningfully to the development of students' problem-solving and numeracy skills.

Influential cases were examined through boxplot inspection and analysis of standardized residual values. The analysis showed that no extreme influential cases were detected in the gain-score distribution. Therefore, the mean differences and effect size estimates were not driven by a small number of extreme scores. This finding supports the robustness of the interpretation that the experimental group demonstrated greater improvement than the control group.

Overall, the findings indicate that STEM-integrated project-based learning effectively supports the development of students' problem-solving and numeracy skills in the context of circular motion learning. These results have theoretical implications for physics education as well as practical ones. Theoretically, the results support a typology of project-based STEM learning to enhance higher-order thinking and quantitative reasoning through contextual, investigative, and collaborative materials. In practice, this can be used as another pedagogical approach for teachers who want to bridge the gap from physics problems to real-world issues with mathematical reasoning skills.

This study has several limitations. First, as the study was conducted in a single school, and with low sample size; these findings cannot be generalized without replication. Second, this study concentrated on circular motion only; consequently, the use of STEM integrated project-based learning in other physics subjects is another area for further research. Third, although the analysis controlled for baseline differences using ANCOVA, other threats to internal validity, such as selection bias, teacher effect, Hawthorne effect, and test sensitivity, may still have influenced the findings. Fourth, the study focused on cognitive outcomes, namely problem-solving and numeracy skills, while affective outcomes, collaboration, and creativity were not analyzed in depth. Therefore, future research is encouraged to involve larger and more diverse samples, examine the implementation of the model across different physics topics, incorporate stronger controls for teacher and classroom effects, and combine quantitative findings with qualitative evidence derived from student artifacts and classroom observations.

CONCLUSION

This study shows that STEM-integrated project-based learning is significantly more influential than conventional learning in improving students' problem-solving and numeracy skills on circular motion material, as evidenced by the results of descriptive and inferential analysis. Quantitatively, the experimental group achieved N-gain values of 0.81 for problem-solving skills and 0.78 for numeracy skills, both classified in the high category. In the opposite way, it is for control group that got N-gain of 0.48 and 0.45 which are the modulation of medium category. ANCOVA showed a significant difference between both groups ($p < 0.05$), with large effect sizes for problem-solving skills (Cohen's d =1.48) and numeracy (Cohen's d =1.36). This implies that pure STEM integrated in project-based learning has a significant impact on structuring student solution construction abilities including study and analyzing problems, designing solutions and implementing strategies, and finally assessing outcomes. Furthermore, it does well to improve students' numeracy skills by reinforcing their decoding of information (such as graphs), the application and modeling of mathematical concepts in physics, the analysis of relationships between variables governed by read or obedience laws, and expressing results in a coherent manner.

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