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The Implementation of the Problem-Based Learning Model to Improve Students' Critical Thinking Skills in Newton's Laws

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Abstract— *Critical thinking is an essential competency in 21st-century physics learning, yet classroom practice is still often dominated by teacher-centered instruction. Problem-Based Learning (PBL) is widely proposed as a student-centered alternative that engages students in authentic problems. This article aimed to examine the theoretical foundations, characteristics, and implementation of PBL for developing the critical thinking skills of high school students, with Newton's Laws as the learning context. The study was conducted as a literature review supported by a bibliometric approach, in which relevant publications were searched with Publish or Perish, screened, mapped with VOSviewer, and managed with Mendeley. The review showed that PBL is rooted in constructivism and is characterized by real-world problems, interdisciplinary links, authentic inquiry, tangible products, and collaboration. Implementing PBL required teacher preparation, particularly in managing the transition to group work and in teaching social and group skills, and it was carried out through a five-phase syntax that begins with orienting students to the problem and ends with analyzing and evaluating the problem-solving process. Previous studies reported that PBL improved students' critical thinking in physics and other science subjects. It was concluded that PBL is a relevant alternative for strengthening critical thinking in physics learning, and empirical testing on Newton's Laws is recommended for future research.*

Keywords— Problem-Based Learning, Critical Thinking Skills, Newton's Laws, Physics Learning, Bibliometric.
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1. Introduction

Physics education requires students not only to understand theoretical concepts but also to apply them in solving real-world problems. One of the essential competencies that should be developed through physics education is critical thinking, as it enables students to reason logically, analyze information, and reflect on natural phenomena. However, students' critical thinking skills remain relatively low in classroom practice. Many students tend to memorize formulas without fully understanding their applications, particularly in Newton's Laws, which involve both conceptual understanding and practical application.

Various instructional approaches have been developed to improve students' critical thinking skills. One model considered effective is Problem-Based Learning (PBL), which emphasizes contextual problem-solving to encourage students to think critically, collaborate, and develop solutions through scientific inquiry. Given these characteristics, PBL is considered capable of fostering conceptual understanding and higher-order thinking skills, making it suitable for physics education.

Although numerous studies have investigated the implementation of PBL, their findings and research directions vary, and relatively few studies have comprehensively mapped research trends, topics, and patterns concerning high school students' critical thinking skills [1]. This situation highlights the need for a review that examines the development of research on PBL for improving critical thinking skills in physics education, particularly in the context of Newton's Laws. Furthermore, teachers and prospective teachers need to understand the theoretical foundations, characteristics, and implementation procedures of PBL to apply the model

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appropriately.

This article aims to examine the theoretical foundations, characteristics, and implementation of PBL for developing critical thinking skills in physics education, particularly in Newton's Laws, supported by a bibliometric approach using Publish or Perish, VOSviewer, and Mendeley. The findings are expected to provide a reference for developing more effective and innovative physics instructional strategies while identifying relevant opportunities for future research.

2. Method

This study employed a literature review supported by a bibliometric approach to examine the development of research on the implementation of PBL to improve critical thinking skills in Newton's Laws. The bibliometric approach was selected because it provides a quantitative overview of research landscapes, thematic relationships, and the contributions of authors and journals in a particular field. The review was conducted through the following four stages.

1. Literature retrieval. Publications were retrieved using Publish or Perish (PoP) from the Google Scholar database using the keywords "Problem-Based Learning," "critical thinking skills," and "Newton's Laws," covering publications from 2020 to 2024.
2. Data screening and processing. The retrieved records were screened to remove duplicate entries and irrelevant publications. The selected data were then exported in CSV format for further analysis.
3. Bibliometric analysis. VOSviewer was used to map keyword co-occurrence, co-authorship, and co-citation networks. The resulting visualizations were used to identify major themes and research developments concerning PBL and critical thinking skills in physics education.
4. Reference management. Mendeley was used to organize the literature, manage in-text citations, and compile the reference list systematically according to the IEEE referencing style.

The literature review findings are presented narratively in the Results and Discussion section.

3. Result and Discussion

3.1 Theoretical Foundations of PBL

Twenty-first-century education requires competencies that extend beyond knowledge acquisition to include critical thinking, creativity, collaboration, and communication. These demands are consistent with UNESCO's four pillars of education: learning to know, learning to do, learning to be, and learning to live together. These pillars emphasize the development of higher-order thinking skills (HOTS). In physics education, critical thinking is particularly important because physics is not merely a collection of formulas and concepts; it also requires an in-depth understanding of relationships among concepts and their applications in everyday life [2].

Nevertheless, physics instruction is still frequently dominated by teacher-centered lectures. Such practices position students as passive recipients of information, limiting their participation in scientific reasoning, reducing opportunities to develop problem-solving skills, and making it difficult for them to connect physics concepts with real-world phenomena [3].

Critical thinking is the ability to analyze, evaluate, and draw conclusions from information logically and systematically. According to Ennis [4], critical thinking involves identifying problems, analyzing arguments, evaluating evidence, and drawing rational conclusions. In physics education, these abilities are essential because students must do more than memorize formulas; they need to understand the physical meaning underlying equations and apply them to real-world situations [5].

One approach to improving critical thinking skills is to implement instructional models that encourage active participation and intellectual engagement. PBL is an innovative instructional model that emphasizes authentic problem-solving as a means of developing higher-order thinking skills. In this model, teachers act as facilitators who guide students in constructing knowledge through exploration and group discussion [6].

PBL presents challenging problems that encourage students to learn and work collaboratively to develop solutions, thereby creating interactions between stimuli and responses [7, pp. 149–150]. This model aims to help students deal with real-life situations and learn about adult roles [8, p. 398]. Kurniawan and Wuryandani [9, p. 12] explain that problem-based learning is "a form of learning grounded in the constructivist paradigm that places students at the center of learning and emphasizes the learning process."

PBL follows a systematic sequence of instructional stages: orienting students to a problem, organizing students for learning, guiding investigations, developing and presenting products, and analyzing and evaluating the problem-solving process. Through these stages, students not only acquire theoretical knowledge but also learn to apply physics concepts to authentic problems relevant to their everyday lives [10].

Several studies have supported the effectiveness of PBL in improving critical thinking skills. Yulianti [11] reported that implementing PBL in teaching Newton's Laws improved students' critical thinking skills by up to 35%. International studies identified through Scopus and Dimensions have also indicated that problem-based learning can enhance students' analytical abilities and scientific reasoning across various science education contexts [12].

Therefore, PBL can serve as an alternative approach to addressing students' low critical thinking skills in physics education. By engaging students in learning activities centered on authentic problems, PBL encourages them to think systematically, logically, and reflectively, enabling them to develop a more meaningful understanding of physics concepts [13].

3.2 Characteristics of the PBL Model

PBL is an instructional approach that uses real-world problems as a context for developing students' critical thinking and problem-solving skills while helping them acquire knowledge and concepts relevant to the subject matter [14]. Accordingly, PBL

can be understood as a model that introduces students to real-world problems from the beginning of the learning process, stimulating their motivation to learn and encouraging them to work collaboratively toward solutions.

According to Arends [8, pp. 398–399], the characteristics of PBL are as follows.

a. Problems are derived from real-world situations. The problems presented originate from everyday life, enabling students to formulate questions and identify various possible solutions.
b. Interdisciplinary learning. Learning activities integrate multiple disciplines, allowing students to approach and solve problems from different subject-area perspectives.
c. Authentic investigation. Students engage in genuine inquiry activities that follow scientific methods.
d. Production of tangible outcomes. Students develop authentic products or demonstrate their problem-solving outcomes, which can subsequently be presented or shared with others.
e. Collaboration. Students work together and motivate one another to solve problems, thereby developing their social and collaborative skills.

3.3 Implementation of the PBL Model

PBL is student-centered; therefore, students need to adapt to their roles as active participants in the learning process, while teachers must adequately prepare for this instructional transition. According to Arends [8, pp. 381–385], involving students in learning groups and presenting them with challenging problems may create significant difficulties if these aspects are not properly managed. Teachers can implement several practical strategies to facilitate this transition.

a. Displaying the main steps for group formation. Teachers can write the essential instructions for forming groups on the board. These visual cues help students move to their respective groups more efficiently.
b. Providing clear instructions. Teachers should communicate directions clearly and ask two or three students to paraphrase them. This strategy helps other students understand the instructions while providing feedback to the teacher regarding their clarity.
c. Designating group locations. Teachers should clearly identify where each learning team will work. Students tend to gather in easily accessible areas, which may result in uneven group distribution. Designating specific locations helps establish effective small-group arrangements.

Many students are not accustomed to working cooperatively. Cooperative learning enables students to work together in small groups but also requires teachers to explicitly teach social and group skills. Several strategies can help students develop these competencies.

a. Task interdependence. Cooperative learning requires tasks to be structured so that group members depend on one another to achieve a common goal. Tasks are not genuinely interdependent when teachers distribute worksheets to several groups but allow each student to complete and submit an individual response. In contrast, tasks become interdependent when each group completes a shared worksheet containing the names of all its members. Interdependence can also be established by dividing learning materials among group members, assigning different problems whose solutions must be compared and matched through discussion, or distributing distinct responsibilities among members. In a group investigation project, for example, one student may prepare the written report, another may develop the PowerPoint presentation, and another may deliver the presentation. Although each member has a specific responsibility, the group's success depends on the cooperative contributions of all its members.
b. Social skills. Teachers should not assume that students already possess the social and group skills necessary for effective cooperation. Students may not know how to interact appropriately, organize cooperative actions, coordinate members' contributions, or evaluate their group's progress toward its goals. Social skills are behaviors that facilitate successful interpersonal relationships and enable individuals to work effectively with others. Children develop these skills through interactions with parents, caregivers, peers, neighbors, and educators. However, some children and adolescents may still have difficulty sharing, participating, and communicating effectively. Therefore, teachers need to support the development of these competencies. Communication skills are particularly important because cooperative learning groups cannot function effectively when communication breaks down.
c. Group skills. Before students can work together effectively, they need to become familiar with one another and respect individual differences. Building teamwork and mutual concern among group members is an important responsibility of teachers in cooperative learning. A simple strategy is to ask students to learn the names of all group members and collectively choose a group name. A positive team identity can be developed in three ways: becoming familiar with group members, allowing each member to express opinions about how the group should function, and establishing shared goals.
d. Teaching social and group skills. Teachers need to demonstrate and model appropriate social and group behaviors, provide opportunities for students to practice these skills, and give feedback on their implementation.

Like other instructional models, PBL is implemented through a specific instructional syntax. According to Arends [8, p. 397], PBL consists of five phases: (1) orienting students to the problem, (2) organizing students for learning, (3) guiding individual or group investigations, (4) developing and presenting work, and (5) analyzing and evaluating the problem-solving process.

Li Zhiyu [15, pp. 289–290] divides PBL into three stages. The first stage involves designing, presenting, and examining the problem. Problems are central to PBL, and their quality influences learning outcomes. The second stage involves independent learning and problem-solving. When students lack sufficient knowledge or skills, they can narrow the scope of the problem and divide responsibilities among group members. After completing their individual tasks, students analyze the problem, compare their

findings, and select the most feasible solution. The third stage involves summarizing, evaluating, and presenting the results. Once the problem has been solved, each group prepares a summary and evaluates its findings.

Based on this discussion, the stages of the PBL model can be synthesized as presented in Table 1.

Table 1. Syntax of the PBL Model

Phase	Teacher Activities	Student Activities
Orienting students to the problem	The teacher explains the learning objectives, outlines the essential requirements and resources, and motivates students to participate in problem-solving activities.	Students understand the learning objectives, prepare the necessary resources, and get ready to engage in problem-solving activities.
Organizing students for learning	The teacher helps students define the problem and organize learning tasks related to it.	Students define the problem and prepare to undertake the associated learning tasks.
Guiding individual or group investigations	The teacher encourages students to collect information, conduct appropriate experiments, and seek explanations and solutions.	Students collect information, conduct appropriate experiments, and develop explanations and solutions.
Developing and presenting work	The teacher guides students in preparing relevant products, such as reports, videos, or models, and supports them in presenting or sharing their work with classmates.	Students plan and prepare their products and distribute responsibilities among group members.
Analyzing and evaluating the problem-solving process	The teacher helps students reflect on their investigations and the processes used to solve the problem.	Students reflect on their investigations and evaluate the problem-solving processes they have used.

4. Conclusion and Recommendations

PBL is a student-centered instructional model grounded in the constructivist paradigm that presents real-world problems as stimuli for learning. Its main characteristics include authentic real-world problems, interdisciplinary connections, authentic investigation, the production of tangible outcomes, and collaboration among students. Implementing PBL requires adequate teacher preparation, particularly in managing students' transition to group-based learning and explicitly developing their social and collaborative skills. The learning process follows five instructional phases. Based on the literature review, PBL represents a relevant alternative for developing critical thinking skills in physics education. Further research is recommended to empirically investigate the effectiveness of PBL in teaching Newton's Laws.

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