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Problem-Based Learning versus Traditional Learning in Physics Education for Engineering Program Students

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Abstract: Problem-based learning (PBL) is an educational method which involves learning by solving real problems. However, applying a PBL approach to engineering subjects in some cases became a challenging issue. Thus, it is important to determine the best ways in which engineering students can learn physics more effectively and solve problems relevant to their daily lives. The main aim of this study was to compare the final assessment grades in a physics course for students in the engineering program using PBL and traditional learning (TL) methods. The advantages and disadvantages of PBL and TL methods from the practical experience of lecturers are also presented. The study presented data of 460 first-year engineering students taking the physics course at Kaunas University of Technology. The information presented in this study is based on the insights, observations, and individual experiences of the authors as teaching staff. The results indicated that the application of the PBL method allows for enhancement in the teamwork, presentation, and critical thinking skills in physics. However, the TL method promotes the individual learning skills and wider theoretical knowledge in physics of students and is more suitable when the exam only includes closed-ended questions.

Keywords: problem-based learning; traditional learning; physics; engineering students; exam grade

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1. Introduction

In the rapidly advancing age of technology, where innovations shape the world, the importance of learning physics cannot be overstated. Physics, as a fundamental science, plays a crucial role in understanding the principles governing the natural world and underpins the technological marvels that surround us [1–3]. By fostering problem-solving skills, technological literacy, and a spirit of innovation, physics education prepares individuals to navigate the challenges and opportunities presented by our technologically driven world. Embracing the studies of physics is, therefore, an investment in the future, ensuring that individuals and societies are well-equipped to thrive in the dynamic landscape of technology [4–6].

There are several methods of education delivery in physics courses. In traditional learning (TL), lectures are delivered by the teacher presenting information to the students. Traditionally, they can be effective when combined with interactive elements, demonstrations, and opportunities for students' questions and discussions [7–10].

In problem-based learning (PBL), students are presented with real-world problems and work in teams in order to find solutions. This method promotes critical thinking, problem-solving skills, and the application of theoretical knowledge to practical situations [8,11–18].

Additionally, there is inquiry-based learning (IBL), which, in education, refers to an approach where students are actively engaged in the learning process through questioning, exploration, and problem solving. It emphasizes student-driven investigation and critical thinking [2,19,20].

Realizing the importance of effective physics education, a new method of physics teaching and improvements in pre-existing methods are constantly being sought. Efforts are made to ensure that the learning methods are not only of high quality but also attractive to learners. All the aforementioned learning methods have their advantages and disadvantages, and which of them is more appropriate in a particular society is debatable. The analysis of learning results (self-evaluation data, midterm exam grades, or exam grades) is one of the ways to objectively evaluate this problem.

The traditional group learning and PBL of two classes were compared in the study performed by Anderson II, J. C. [21]. The results indicated that the post-test mean score and the pre-test mean score of the PBL class were better compared to the results obtained in the TGL class [21]. In addition, A.S. Argaw et al.'s [11] study indicated that schools must adapt the PBL method in physics very carefully in order to improve students' achievements. Also, the authors stated that the use of the PBL method in physics was a more effective teaching method to improve experimental skills compared to the conventional teaching method. However, the application of PBL did not increase the motivation of students to learn physics. Mundilarto, Helmiyanto Ismoyo [12] observed that the PBL model could improve the learning achievement of students and promote critical thinking skills when experimental works or practical tasks in physics are incorporated. A. Tiwari et al. [22] also compared data on the critical thinking skills of students between PBL and lecture learning. Two classes of similar numbers of students were compared by using the California Critical Thinking Disposition Inventory (CCTDI). The authors obtained an overall improvement of the PBL class in the CCTDI (with $p = 0.0048$) [22]. D.T. Tiruneh et al. [6] analyzed the critical thinking skills of students in physics. The pre-test and post-test mean scores in the experimental group in determining critical thinking increased from 22.1 to 59.84, respectively. Meanwhile, the mean scores for the critical thinking skills in the pre-test and post-test results in the case of the control group were 17.34 and 46.72, respectively. It should be noted that critical thinking skills were improved in both classes. However, the higher achievement was obtained using PBL. M. Liu et al. [23] also observed that the scientific knowledge of students increased using the problem-based learning method. The increase in knowledge was obtained not only for gifted students but also for the students who had below-average abilities in terms of economics, social skills, and education. F. Herliana et al.'s [24] research demonstrated that the average value of learning outcomes of female students was higher in solving physics tasks in the cognitive domain compared to male students when the blending problem-based learning model was used. J.T. Ajai and I.I. Imoko [25] observed that the achievements of female and male students were very similar when a problem-based learning model in mathematics was used. This observation demonstrated that the application of PBL in physics improved the soft skills of students, such as self-directed learning, teamwork, leadership, and good presentation skills. One of the problems of engineering students in solving assignments in PBL physics was the lack of teamwork among team members [26]. J. H. C. Moust et al. [17] analyzed students' study behaviors in various PBL programs. The authors indicated that insufficient time for self-study, minimal preparation prior to the group meeting, inadequate time devoted to researching the information regarding the given topic, omission of brainstorming or group discussions, and superficial analysis of the problem tasks in the final reports are the main problems in PBL.

Overall, the studies primarily showed that the application of problem-based learning in physics lectures allows for an increase in students' critical thinking, presentation, and problem-solving skills, but its application also raises several new challenges.

The aim of this study was to indicate the advantages and disadvantages of problem-based learning and traditional learning (conventional) physics modules for engineering program students from the perspective of teaching staff, and to determine the effect of the used learning methods on the academic achievement of students.

2. Materials and Methods

The study was provided with two groups of participants, one of which was the PBL group (303 students), and the other was the traditional (control) learning group (158 students). The results presented in this research include the physics course achievements of the first-year students of the Faculty of Electrical and Electronics Engineering (traditional learning) and the Faculty of Informatics (problem-based learning). The physics course belongs to the core course of their Bachelor's degree study program and is obligatory for students in engineering programs. The physics course material consisted of Classical Mechanics, Oscillations and Mechanical Waves, Thermodynamics and Molecular Physics, and Electrostatics, Electric Current, and Electromagnetism topics. The lowest positive grade, indicating that the student successfully passed the physics course, is 5 (sufficient), while the highest possible grade is 10 (excellent).

The physics module structure for the problem-based learning contained 16 academic hours of theoretical lectures, 16 academic hours of practical lectures, and 48 academic hours devoted to the solvation of the real problem tasks. The duration of the semester is 16 weeks. Small teams consisting of four to five students were formed. Students were divided into working teams randomly, and after completing each problem task, the new teams were formed randomly again. After receiving the real problem task, student teams were given time (1 academic hour) for the analysis of problems, brainstorming, definition of the problem, setting self-learning goals, creating a work plan and strategy, and sharing of roles. Team members elected a group leader and a secretary. The elected leader of the team distributed the work and responsibilities of the members in performing problem-based tasks. In addition to the given problem task, the student group had to perform two laboratory works related to the received problematic task and prepare a joint report. The four problem-based tasks were given to each team of students. Four weeks (16 academic hours of lectures) were given to solve the problem, prepare a final report, present it, and defend it. Each student completed four problem-based tasks during the learning course of physics. The final mark was given for the explanation of their problem-solving approach, presenting results, discussing any challenges faced, and the quality and correctness of answers to the questions. Students also evaluated each other, depending on their input to the preparation of the final report and work spent on solving the problem task. The settlement of theory questions and practical tasks took place four times during the semester. The assessment for theoretical questions and practical tasks was carried out concurrently and was graded as a combined score. It should be mentioned that one lecturer worked with a group of 10 to 20 students. Students were assessed for various tasks, and the final score consisted of several contributions: grade given for theoretical question answers and solving the problem exercises (30%), preparation of the PBL report (30%), presentation and defense of the PBL report (30%), and the self-evaluation of group members (10%).

This grade structure ensures that the students are assessed on various aspects. The impact of one PBL task on the final grade of physics is 20%. The structure of the final grade evaluation when the PBL method was used is presented in Figure 1. The final exam in the physics module is a test of consisting of closed-ended theoretical questions and practical tasks. The contribution of the exam grade to the final grade of the physics subject was 20%. Lecturers play an important role in providing an effective learning environment, giving consultations, and providing similar practical exercises related to given problem tasks.

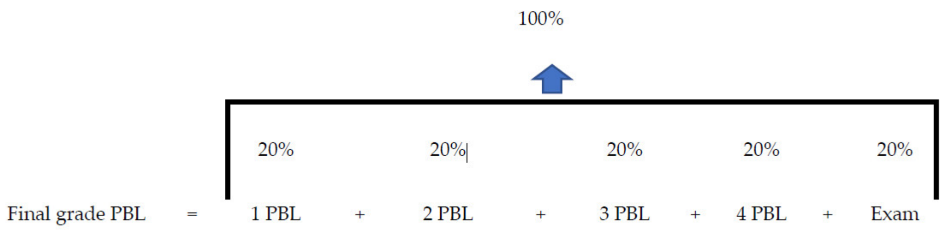

Figure 1. The structure of the final grade evaluation in PBL method.

The physics module structure when the traditional (conventional) learning was used contained 32 academic hours of theoretical lectures, 16 academic hours of practical lectures, and 32 academic hours devoted to laboratory works. The duration of the semester is

16 weeks. In the traditional learning method, students had twice as many theoretical physics lectures as in the PBL method. During the semester, students are required to complete 8 laboratory works, prepare their reports, and defend the presented laboratory work. Laboratory work was carried out in groups of two students or individually, while laboratory reports were prepared, presented, and defended individually. It should be mentioned that one lecturer worked with a group of 8 to 16 students through laboratory works. During the semester, students have one intermediate assessment of theory and two assessments of practical solving tasks (the contribution of each task is 10%). The final exam on the physics module is a test consisting of closed-ended theoretical questions and practical tasks. The contribution of the exam grade to the final grade of the physics subject was 30%. The impact of each settlement on the final grade in TL is presented in Figure 2. The main role of the lectures in TL was to present and explain the theoretical basis of physics, solve practical exercises, and give consultations related to laboratory works.

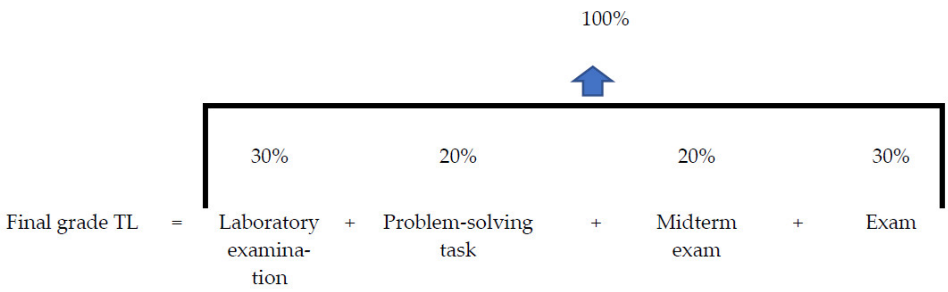

Figure 2. The structure of the final physics grade evaluation in TL method.

3. Results and Discussions

The final grade depends only on the individual effort and knowledge of the student when traditional learning is used. During laboratory work, more practical skills are acquired as students work individually or in pairs. Individual work ensures that the student is responsible for their contributions, making it easier to assess individual performance, and allowing them to concentrate more deeply on the given task or problem. The performance of the work takes longer, or with insufficient knowledge, part of the task may not be completed or correctly solved. One common obstacle obtained in the traditional learning of some students was staying motivated and disciplined. It was a challenge for some of the students to correctly manage their learning time and keep to the scheduled deadlines.

The final grade depends on the individual effort and knowledge of the student and on the result of teamwork when PBL is used. Less practical skills are acquired during laboratory work, as students work in teams of 4–5 people. With more group members, individual accountability is reduced, making it difficult to measure the real contribution of each student to the final report and result. Larger student groups faced more complex decision-making processes, which led to disagreements, conflict situations, and delays in reaching consensus. Tasks and work were distributed among team members, so the task was performed more efficiently and quickly. Students in teams have different knowledge in mathematics and physics, practical experience, and skills, thus increasing the diversity and reducing the time of approaches applied to problem solving. Students can share experiences with each other and learn more from each other.

Despite the mentioned advantages of the PBL method, there were also new issues for lecturers and students raised. The problems were that when using PBL teaching, there was not an even distribution of work and tasks among students in some groups. Some students lacked the knowledge or motivation to complete the given problem-based learning tasks. There were groups where a group member was late for the assigned task or did not complete it. Therefore, more active, responsible, and motivated students had to complete additional tasks in order to successfully solve the given problem. This led to internal conflicts among group members. Students refused to share a final report or perform a presentation, along with a student who avoided completing assignments. Also, when new groups were formed to solve the next problem-based task, other group members did not want to have an unmotivated and irresponsible student in their team. Since the given tasks were focused on solving a real problem by applying certain physical laws, some students did not try to go deeper into theoretical knowledge and laws of physics unrelated to their task. Also, the skills and knowledge of group members depended on the level of knowledge obtained in school. This led to the fact that the analysis of the problematic tasks of some groups in the final reports and presentations was superficial. To force and motivate the student to perform his tasks was one of the challenges that lecturers faced when problem-based learning was used. The difficulties in controlling the group progress and participation, especially during self-study time, were observed in different studies during the application of the PBL method [6,11,22]. The lecturers indicated that the application of the PBL method in a physics course required more time to be spent on the evaluations of the students' assignments and achievements. It is associated with the fact that the evaluations of PBL reports may involve not just assessing the final answer but also understanding the thought process, problem-solving methods, and the application of fundamental physics laws. Also, students often apply diverse solutions to the same task. Evaluating these solutions requires a more delicate approach, as there are multiple correct ways to solve a given problem. The assessment of the individual contribution of the student during the presentation of the final reports also required extra time. Some students indicated that learning the theory of physics, solving the problem-based tasks, and preparing the PBL reports took quite a lot of time compared to other courses where traditional learning was used. It was observed that the application of PBL in physics helped to improve students' conceptual understanding of physics, but engagement and time spent on this course were higher compared to traditional learning in the physics courses [14].

The final exam grades of students using PBL and TL methods are presented in Figure 3. The results indicated that the final physics exam grades related to sufficient (23.7%) and satisfactory (30.3%) evaluations in the PBL method were very high and represented more than half of the total students' scores. Meanwhile, only ~8.2 percent of students in the TL method received an exam evaluation of sufficient. Nineteen percent of students passed the final exam with a satisfactory grade. The number of evaluations associated with highly satisfactory was 22.7% and 23.4% for the PBL and TL methods, respectively. It should be noted that about half of the students (49.4%) who studied using the TL method obtained a score of good or higher on the physics exam. Meanwhile, the number of students with similar levels of knowledge and skills in the PBL classes was only ~20.4% (Figure 3). The average grade of the final exam of the students using traditional learning was ~7.44. Meanwhile, the average grade of the final exam of the students was ~6.50 when the PBL method was applied. The results showed that using PBL teaching, the students average scores were ~13% lower compared to the students' scores obtained using TL method.

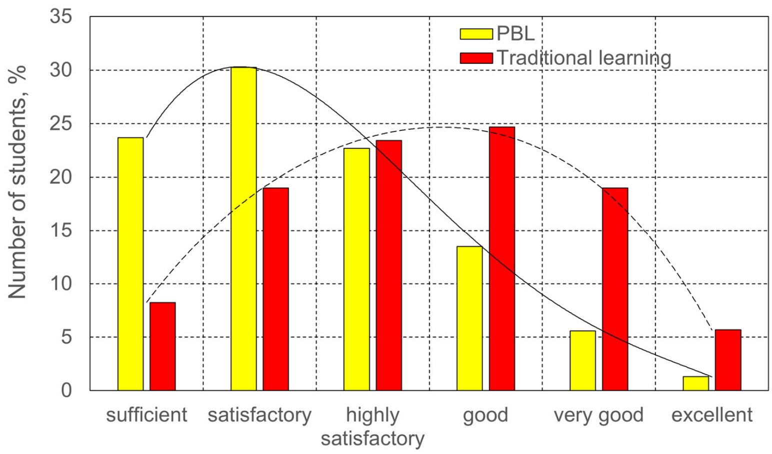

Figure 3. Variation in physics exam grades of students using PBL and TL methods.

The obtained results showed that the final exam, which was focused on testing theoretical knowledge of physics and solving practical problems, was more favorable to students who used the TL method (Figure 3). Several factors such as structured learning, routine and discipline, familiarity with the exam format, a higher number of theoretical lectures, and more direct interaction between lecturer and student could contribute to this result. Traditional learning students worked individually and usually had more interaction with lecturers, especially during laboratory work. Students had received more explanations, clarifications, and additional support from lecturers, addressed to improve individual learning gaps. Traditional learning usually follows a set routine, with scheduled activities and assignments. Thus, students can develop strong study habits and discipline, contributing to more effective exam preparation. A structured curriculum with clear milestones and assessments is used, and students can gain a more systematic and broader understanding of the theoretical concepts and problem-solving techniques. During the theoretical physics lectures, various self-explanatory animations and demonstrations explaining physical phenomena were shown. The self-explanatory animations play a vital role in education by enhancing understanding, engagement, and retention of physical phenomena. Animated demonstrations aid in clarifying concepts and enable students to grasp the underlying principles of physical phenomena better. Animations can be a bridge between theoretical physics concepts and real physical processes occurring in the environment, which increases the effectiveness of learning and the acquisition and understanding of physics principles. Since students who studied according to the TL methodology had more theoretical lectures compared to the students when the PBL methodology was used, the effect of self-explanatory animations on the achievements of students was greater. The final exam structure closely aligns with the format of midterm exam assessment and self-evaluation tests given during the theoretical lectures.

The specificity of the PBL method may also contribute to the students' lower average grade on the exam. The final exam had a different format compared to assessments used in PBL studies. The exam required more direct recall of specific theoretical physics concepts, so students who were primarily engaged in the PBL method might find it challenging to adapt to the different learning styles. The exam required a broader knowledge and a more comprehensive understanding of the physics course content. The PBL method encourages a deep understanding of specific problems related to given problem-based tasks, but limits the wide coverage of theoretical physics knowledge. Thus, some of the students were not properly prepared for the exam, because the individual learning skill was not sufficiently promoted by the PBL method. Student teamwork in groups may also result in unmotivated students' personal input on work contributions and poorer theoretical knowledge being overshadowed by more motivated and higher skilled students' work and theoretical knowledge. It creates the illusion that the knowledge of all group members during the implementation of the PBL tasks is similar, but test results revealed that about a half of the students had only theoretical knowledge evaluated as satisfactory and sufficient. Teaching is performed according to the same program of the physics module (topics, typical tasks, laboratory works), except that during the traditional learning, the physical laws themselves and the nuances of their application are deepened, while during PBL, much more knowledge is gained about the practical implementation of the laws of physics. A.S. Argaw et al. [11] also determined that the PBL method improved the problem-solving skills of students, but the motivation to learn physics remained similar when the PBL and traditional learning were used. A similar tendency was obtained in our studies. It was obtained that the motivation to learn physics does not depend on the gender of students [11]. Despite the fact that the PBL was more effective in problem-solving skills than the traditional teaching method, the students' motivation to learn physics remained similar in both cases and did not increase as expected [11,12,27]. Students were motivated to solve the problem-based tasks, but the desire to learn additional material related to more basic knowledge of physics remained stagnant. This could be one of the reasons why the exam results of PBL students were lower compared to TL students. It was demonstrated that the active participation of the lecturers in the learning process significantly improved the achievements of the students. It showed that the achievements of students were higher when teachers were actively involved in their learning process (additional consultations, advice, etc.), compared to the students' assessments when the lecturers were not involved [12]. It was demonstrated that the achievement of the students is higher when learning physics via computation focus was used [28].

The distribution of the final grades of students in physics when the PBL and TL methods were used is given in Figure 4. The final average grade of learning outcomes was ~8.00 (good) and ~7.50 using the PBL and TL methods, respectively. It can be seen that during both learning methods, students do not obtain sufficient final grades. A highly satisfactory final grade was obtained by ~39.9% of students in the TL method. Meanwhile, the dominant final grade in physics in the PBL method was good, and as many as ~47.5 percent of students were assessed with this evaluation. The number of evaluations associated with very good was 21.5% and 11.4% for the PBL and TL methods, respectively. The number of students achieving the highest grade was slightly higher in TL of physics, despite the fact that the final average grades were higher in the PBL method (Figure 4). It is interesting to note that the average exam grade results (7.44) and the final grade values (7.50) using the TL method were almost the same. Although the students' exam score in the PBL teaching was lower, the final average grade in physics was slightly higher (~6%) compared to students who used the traditional learning method. The application of the PBL method in physics of engineering program students revealed that evaluation scores of the students are higher when the impact of the practical and problem-based tasks on the final grade is higher. However, the relative significance difference between the exam (6.50) and the final grade (8.00) average values shows that the theoretical knowledge of physics remained moderate and is mainly improved only through physics knowledge related to the given theory part of practical problems. It was demonstrated that the students' grades were higher when the PBL method was used due to a higher improvement in the understanding of physics concepts [18]. However, the authors indicated that the focus of the test was related not to the retention of physics theory, but to understanding and applying concepts in solving practical problems. Also, the authors stated that the higher grades of PBL students could not be assigned to a higher degree of content learned by the student, but due to the more favorable structure of the given test [18]. It was demonstrated that the specific test should be created and used for measuring students critical thinking skills in physics [6]. P. Celik et al. [29] investigated the influence of problem-based learning on the students' success in a physics course. The authors indicated that the pre-test results of the PBL and TL groups were similar. The research was carried out by dividing students into small groups, depending on the participants' physics course achievements (pre-test results) when the PBL method was used. The "Physics exam" test results obtained at the end of the experimental study indicated that the scores of the participants from the PBL group were statistically significantly higher than the scores of the participants from the TL group. The achievement of better results in the PBL groups was related to improved abilities in teamwork and researching skills. O. Ojaleye et al. [30] indicated that problem-based learning is student-centered because an authentic and original problem engages learners and stimulates their interests. Students work in small teams to tackle the problem, identify learning gaps, and develop viable solutions, and this promotes higher engagement in learning and stimulates the motivation of learning and willingness to solve the given tasks [31]. S. Wilder et al. [32] indicated that the students gained more new knowledge through self-directed learning when the PBL methodology was used. This leads to the development of problem-solving and critical thinking abilities of the students. During PBL teaching, the lecturer is forced to communicate much more often with students while observing the learning process of the students. Thus, the students constantly receive the feedback and feel more satisfied, because they know that their learning process is going in the right direction. M. Sahin et al. and L.K. Heng et al. [8,27] observed that when students have a positive attitude toward a particular subject, they are more likely to achieve better learning outcomes. K.

Aslihan et al. [33] also observed that the PBL was more effective on the improvement of conceptual understanding in learning of magnetism-related topics than the traditional teaching method. The authors stated that an improvement was reached due to the cognitive effects of PBL on the students learning. When the learning environment is established, to improve students' problem-solving and thinking skills, rather than simply memorizing knowledge, students mentally internalize it with meaning. More complex and realistic daily-life problems are used to identify the principles and concepts of physics phenomena necessary for students to learn, as well as to motivate them to study [33]. C. Becerra-Labra et al. [34] indicated that an application of PBL in physics learning significantly improved conceptual learning, enhanced the ability to solve problems, and had a positive effect on students' attitudes and interest in physics.

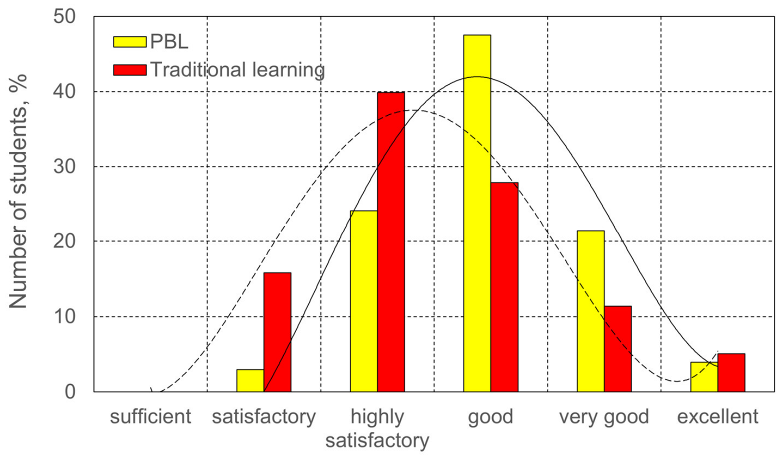

Figure 4. Distribution of the final grades of students in physics using PBL and TL methods.

Several studies demonstrated that the PBL has a wide range of advantages, such as being student-centered; inducing deep, active, and meaningful learning; and developing problem-solving and creative and critical thinking skills [11,12,29,31–33]. Our research also showed that these skills of students improved more when the PBL methodology was used. The performed study confirmed that the PBL method prioritizes the enhancement of application and problem-solving abilities over rote memorization of theories and physics laws.

4. Conclusions

The mean dispersion of exam grades showed that traditional learning was a more effective method for testing the physics knowledge of students using the closed-ended question test (with existing options) method. The assessment of physics knowledge using the closed-ended test method was not suitable for estimating the knowledge (or skills) of students taught by the PBL method. The obtained results showed that using the TL method, students' theoretical knowledge of physics was better and wider, while using the PBL method improved their practical skills and deepened their understanding of specific physics topics. The results demonstrated that the mean dispersion value of final grades was higher in the PBL method. The authors believe that the PBL method is a more effective method for learning physics for less motivated students because students are forced to work and learn continuously throughout the semester, and it could improve their motivation in learning physics. Meanwhile, the less motivated students start learning just before the scheduled assessment deadline when the traditional learning method is used. It should be noted that for highly motivated and well-skilled students, the choice of the learning method does not affect their final grades. Implementation of the PBL method in physics required more time investment for lecturers compared to the TL method.

The recommendation for further study would be to perform research on the students' self-reflections to support or reject the findings/claims made by the authors in the study.

This would provide more detailed knowledge of the impact of the learning methods used on student achievement. Additionally, in order to obtain quantitative data on which of the applied learning methods allows students to achieve higher learning outcomes, it is recommended to perform pre-tests at the beginning of the physics course and post-tests at the end of the physics course.

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