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**Research Article**

# Effect of project-based learning on middle school students' conceptual understanding of mechanics: A quasi-experimental study

**Zhomart Naushabekov** [1]
0000-0001-6970-0652

**Samat Maxutov** [2]
0000-0002-4453-5512

**Aizhan Mansurova** [3*]
0000-0001-6544-5340

**Nursultan Japashov** [2,4,5]
0000-0002-6338-8132

[1] Department of Mathematics, Physics and Informatics Teaching Methods, Abai Kazakh National Pedagogical University, Almaty, KAZAKHSTAN
[2] Department of Pedagogy of Natural Sciences, SDU University, Almaty, KAZAKHSTAN
[3] Department of Physics, Nazarbayev Intellectual School of Physics and Mathematics in Almaty, Almaty, KAZAKHSTAN
[4] Educational Theory and Practice Department, University at Albany, New York State University, Albany, NY, USA
[5] Physics and Technology Faculty, Al-Farabi Kazakh National University, Almaty, KAZAKHSTAN
[*] Corresponding author: mansurova_a@fmalm.nis.edu.kz

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**ABSTRACT**

This research investigated the effect of project-based learning (PjBL) on students' conceptual understanding of mechanics. For this purpose, a quasi-experimental research design was conducted with 50 ninth-grade students at Nazarbayev Intellectual School in Kazakhstan. We used the force concept inventory test to measure students' conceptual understanding. The results were analyzed using parametric and non-parametric t-tests, ANCOVA, and the goodness of fit analysis tests. After analyzing the pre- and post-test, the results of t-tests and ANCOVA showed that PjBL positively affected students' conceptual understanding of mechanics, particularly their understanding of Newton's first law, Newton's second law, Newton's third law, the superposition principle, and types of forces. The goodness of fit analysis showed that PjBL is highly effective in enhancing students' understanding of concepts related to types of forces.

**Keywords:** project-based learning, effect of PjBL on conceptual understanding, PjBL in mechanics, PjBL with FCI, PjBL in physics

## INTRODUCTION

Project-based learning (PjBL), is an educational strategy that is employed in education, including the field of physics. Instead of passively absorbing knowledge from traditional lectures, PjBL involves students actively dealing with real-life problems. In the context of physics education, PjBL consists of providing students with relevant and meaningful physics-related challenges. These challenges typically reflect real-life situations where physics concepts and principles can be applied to find solutions. Students work individually, in smaller groups, and in bigger groups to explore and understand the underlying physics principles required to address the problem effectively. The study done by Afriana et al. (2016) found that the implementation of PjBL in

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science classes enabled students to tackle real-life contextual problems by going through a structured process, including project planning, solution development, and effective communication of the findings. Diana and Sukma (2021) analyzed that the implementation of PjBL in science classes has been shown to enhance students' mathematical creative thinking skills. This improvement is attributed to several aspects of the learning model. First, the constructivist aspect allows students to build new ideas and concepts based on their existing knowledge. The discovery stage further promotes creative thinking by encouraging students to collaboratively solve problems and design projects. Secondly, the research stage plays a role in fostering creative thinking as students are required to gather information and develop conceptual understanding based on the project. Another study conducted by Goldstein (2016), who used a qualitative phenomenological approach, found that almost all students (about 90%) expressed a feeling of improvement in their perceptions of learning physics due to their experience with PjBL. Students mentioned positive changes in their attitudes towards learning physics. Moreover, 84% of the respondents found the PjBL approach matched their preferred learning styles, with some students highlighting the benefits of collaborative learning and a meaningful learning experience. Overall, the findings suggest that the PjBL approach positively impacted students' perceptions of learning physics and improved their motivation, self-efficacy, and collaborative skills. However, some challenges were identified, including the need for additional support and clear guidelines for students, as well as the instructor's increased workload (Goldstein, 2016; Schwippert et al., 2024).

PjBL has emerged as a promising approach in physics education, offering an innovative way to engage students and promote active learning. This study aims to investigate the effect of PjBL on middle school students' conceptual understanding of mechanics through experimental study. By delving into this topic, the research seeks to address the following key question: How PjBL affects secondary students' conceptual understanding of mechanics?

The significance of this study lies in its potential to revolutionize the landscape of physics education. By exploring the impact of PjBL, educators can gain valuable insights into effective teaching strategies that go beyond traditional lecture-based methods (Baran et al., 2018; Holubova, 2008; Tucker et al., 2024). The findings have the potential to enhance learning outcomes, increase student engagement, and foster critical skills such as collaboration and problem-solving. Moreover PjBL help to facilitate interdisciplinary connections and aligning classroom activities with real-world applications. Despite the growing interest in PjBL as a pedagogical approach, there remains a noticeable lack of comprehensive research specifically focused on its implementation in physics education. While numerous studies have explored PjBL in general education settings and physics classrooms (Baran et al., 2018; Halubova, 2008; Hanif et al., 2019a; Putri et al., 2017; Rozal et al., 2021; Shurin et al., 2021; Widakdo, 2017), limited attention has been given to its investigation of the effects on students' conceptual understanding of specific physics concepts (Shishigu et al., 2017; Tasoğlu & Bakaç, 2014). Furthermore, upon reviewing the literature, it became apparent that there is a lack of research concerning PjBL and its connection to physics education within the context of Kazakhstan. This dearth of research creates an essential opportunity to contribute to the field and expand our understanding of the benefits and challenges of using PjBL to teach physics.

## PjBL in Kazakhstan

In recent years, PjBL has gained significant attention as a promising pedagogical approach in various educational contexts worldwide. However, despite its increasing popularity, there is a notable lack of research focusing on PjBL in the specific context of physics education in Kazakhstan. For instance, Salybekova et al. (2021) investigated students' research skills development through PjBL in biology classrooms using an experimental approach. The study findings state that applying PjBL in Biology classrooms expands students' theoretical knowledge, fosters research skills, and enhances cognitive and creative abilities. Another study done within the Kazakhstani context about PjBL found that teachers and students were unprepared to implement PjBL in Biology classrooms. According to Abishova et al. (2020), there is an urgent need to develop a methodology or guidance for teachers to better implement PjBL. Another study done regarding PjBL in Kazakhstan was conducted by Mussina et al. (2019). The scholars investigated lecturers' conceptual understanding of PjBL and found that instructors at the pedagogical university possess knowledge about PjBL, but they seldom employ this teaching approach. Other studies also investigated PjBL in the Kazakhstani context in relation to different fields of IT discipline (Nurbekova et al., 2020; Yaskevich et al., 2022).

## Force Concept Inventory

The force concept inventory (FCI) is a widely used multiple-choice test to assess students' grasp of physics concepts (Hestenes et al., 1992). However, it has raised concerns about students' poor conceptual understanding of physics. Research using the FCI has shown that students struggle with coherence in their understanding of physics concepts (Fazio & Battaglia, 2019; Savinainen & Viiri, 2008). This lack of coherence suggests they find it challenging to connect related concepts and apply them in different situations. Consequently, the FCI not only evaluates students' conceptual understanding but also emphasizes the need for better teaching approaches to address these issues. By identifying weaknesses through the FCI, educators can tailor their teaching strategies to improve students' conceptual understanding and overall performance in physics. For instance, Fazio and Battaglia (2019) conducted a study at one of the Italian universities among engineering students using cluster analysis methods to analyze their responses to FCI questions. The majority of the students showed a lack of understanding of Newtonian explanations for motions. Many students exhibited a naive conception of force, identifying gravity and motion-related forces but neglecting reaction forces. Misconceptions regarding Newton's third law were prevalent among the student sample. Students had difficulty differentiating between velocity and acceleration, and this impacted on their ability to apply Newton's first and second laws (Fazio & Battaglia, 2019). Other scholars, Savinainen and Viiri (2008), have also found that the FCI can be utilized to evaluate students' conceptual understanding of physics concepts. Their study's results indicate that students showed a well-developed conceptual understanding of Newton's first and third laws but a weaker understanding of kinematics and Newton's second law. Moreover, Savinainen and Viiri (2008) emphasize the significance of addressing weaknesses in students' grasp of physics concepts to enhance teaching approaches.

## PjBL and Conceptual Understanding

PjBL is essential in physics education as it empowers students to actively engage in real-world projects, fostering deeper understanding and application of physics principles through hands-on experiences. Overall, research highlights the significant benefits of using PjBL in teaching areas of physics such as Newton's laws, Newtonian concepts, light, optics, and STEM fields (Ardianti & Raida, 2022; Hanif et al., 2019b; Makkonen et al., 2021; Saldo & Walag, 2021; Saleh et al., 2020; Sumarni et al., 2016). For instance, Ardianti and Raida (2022) found that students' understanding of science concepts improved in various indicators, such as restating a concept, classifying objects according to certain properties, giving examples of the concept, presenting concepts in mathematical representation, developing conditions for a concept, using certain procedures, and applying concepts to problem-solving. The study suggests that implementing a PjBL model with an ethnoscience approach positively impacts students' conceptual understanding of science and fosters their interest and engagement in the learning process. Another study conducted by Hanif et al. (2019a) examined the effect of PjBL on students' creativity, revealing a medium improvement in students' post-test scores for the cognitive dimensions of Bloom's taxonomy, specifically analyzing, evaluating, and creating.

The literature review reveals the positive impact of PjBL on students' conceptual understanding across different subject areas. Studies conducted by Makkonen et al. (2021), Sahin (2010), and Sumarni et al. (2016) demonstrate that PBL effectively engages students in learning, fostering interest and autonomy while promoting collaborative problem-solving and higher-order thinking skills. The implementation of PjBL leads to improved post-test scores and indicators of understanding, with students responding positively to real-world examples and hands-on activities. For instance, Sahin (2010) states that students in the experimental group showed a significant improvement in conceptual understanding of Newtonian concepts after being exposed to PjBL. Moreover, PjBL's alignment with constructionist theories further supports its effectiveness in enabling students to actively construct knowledge (Makkonen et al., 2021; Sahin, 2010). Interesting to note that, PjBL positively increased students' autonomy. Autonomy was associated with increased interest and deeper cognitive engagement in learning physics. Despite some challenges, such as resource limitations and varying student abilities, the evidence suggests that PjBL is an adaptable and rewarding approach to enhancing students' conceptual understanding and skill development in various academic disciplines.

Overall, the PjBL approach in physics not only helps students build a strong foundation in physics concepts but also equips them with essential skills that are valuable in their academic and professional lives. It transforms the learning experience from passive to active, creating more motivated and competent learners. The purpose of doing research related to PjBL in physics is to investigate and understand the effectiveness and impact of using the PjBL approach in physics education. Researchers conduct studies in this area to explore how PjBL can be utilized to enhance students' learning experiences, improve their understanding of physics concepts, and develop essential skills.

## METHODOLOGY

### Research Design

This quasi-experimental research, employing a pre- and post-test design with experimental and control groups, was conducted with 50 ninth-grade students at Nazarbayev Intellectual School (NIS) in Southern Kazakhstan. The research took place during the first semester (from the beginning of September to the end of December) of the 2023-2024 academic year.

### About Nazarbayev Intellectual Schools

The NIS is an independent educational institution that has received accreditation from the Council of International Schools. NIS was established in 2008 by the first president of the Republic of Kazakhstan and consists of a collection of educational facilities. Currently, there are 22 NIS spread throughout the country (Balta et al., 2023).

The primary aim of NIS is to serve as a testing ground for the development, evaluation, research, analysis, and implementation of contemporary educational program models at various levels, including preschool education, primary school, elementary school, and high school.

To enroll in the middle school program and continue their studies at high school at NIS, students are required to successfully pass a specific nationwide selection process. This selection is based on an examination that assesses students' mathematical and Kazakh, Russian, and English language abilities upon completing the $6^{th}$ level of education. Those who pass the selection process begin their studies at NIS starting from the $7^{th}$ level. NIS ensures that all students receive various benefits, including five complimentary meals per day, a school uniform, and free dormitory accommodation for students outside the city center.

NIS has its study program called "NIS-program," which was developed together with the University of Cambridge. However, the physics lessons at NIS are mostly based on A and AS-Level curriculum for middle and high schools, which was developed by the University of Cambridge (Cambridge, 2023). Ninth graders have four academic hours of physics lessons per week and two hours of extra lessons where they can discuss physics topics they did not fully understand during the main lesson or solve complex problems to strengthen their knowledge.

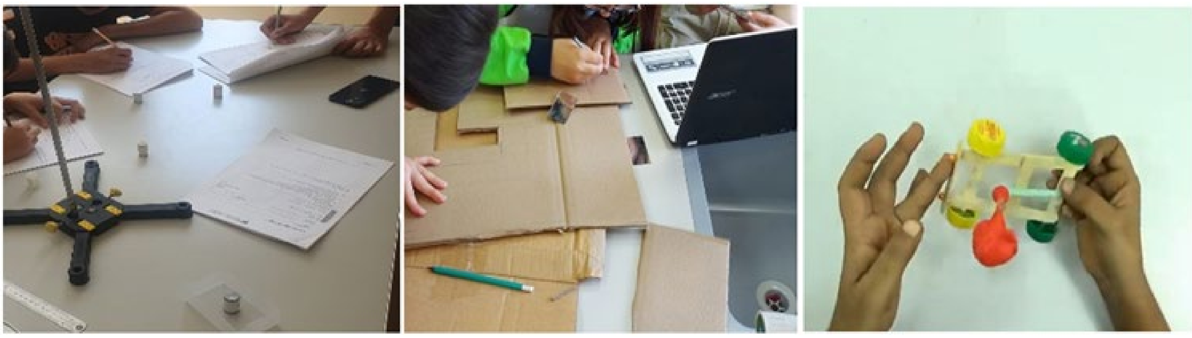
### Research Procedure

For this research, we selected two groups of ninth-grade students–25 students in the experimental group and 25 in the control group, totaling 50 students. We purposefully chose ninth-graders because, according to their curriculum, they begin studying mechanics in September and finish in December.

Before initiating the experiment, both the experimental and control group students were given a paper-based FCI as a pre-test. Students answered the questions without having strong prior knowledge of mechanics, although they were familiar with basic concepts from their seventh-grade physics class. Therefore, we assumed they had some foundational knowledge of mechanics before the experiment began.

None of the FCI items were discussed with the students after they completed the pre-test, and none of them received feedback about their test results. This was a planned strategy for the study because, at the end of the semester, the FCI was administered again as a post-test to compare pre- and post-test results. This strategy allowed us to observe students' progress in their conceptual understanding of mechanics after the experiment and to compare the progress of the experimental group with that of the control group.

During the experiment, students in the control group received traditional physics instruction. The instructor provided basic theoretical materials, explained key concepts of the lessons, demonstrated relevant



(a) (b) (c)

**Figure 1.** Students in the process of assembling balloon bowered car (a) Preparation stage of the project: Students search for information, take notes, and answer conceptual questions for their projects (b) Students sketch and construct their projects (c) Final product: A balloon-powered cart (Source: Authors' own elaboration)

physical phenomena, solved problems, conducted experiments, facilitated class discussions, and assigned homework.

In contrast, the experimental group participated in project-based physics classes. After introducing a new topic, stating the lesson objectives, and giving initial instructions, the instructor divided the students into small groups of 2-3 members and assigned them tasks to develop specific projects related to the topic. Initially, students researched the theoretical background using books, the internet, and other available resources. At this stage, the instructor acted as an advisor, ensuring that all students understood the key concepts of the lesson.

Once students had gathered sufficient information, they developed a plan for their projects and discussed it with peers and the instructor. This planning stage lasted between 40 and 80 minutes, i.e., one to two academic hours. Since ninth graders have four academic hours of physics classes per week, the remaining two hours were dedicated to designing and completing their projects. Students were encouraged to undertake manageable projects that could be completed in 20-30 minutes. These included building small carts, moving or flying objects, and designing computer simulations to model motion and applied forces. One of the examples of students' projects is shown in **Figure 1**.

Throughout the project work, students were allowed to use any relevant online resources. These included simulation platforms such as PhET (2023), lab-based project ideas from Physics Lab (2023) and TeachEngineering (2023), and hands-on activities using household or laboratory materials. After completing their projects, students tested and presented their work to their peers, using lab equipment and multimedia tools as needed.

At the end of the semester, the FCI was administered again for both experimental and control groups as a post-test to evaluate students' progress in their conceptual understanding of mechanics.

Throughout the study, the instructor was responsible for ensuring that students in both the experimental and control groups mastered the lesson objectives related to the following topics in mechanics: motion, free fall acceleration, projectile motion, motion of a falling object in air, Hooke's law, elasticity, Newton's first, second, and third laws, action-reaction, types of forces, superposition of forces, determination of the coefficient of friction, orbital motion of planets, and torque.

## Research Instrument

For this research, we utilized a research instrument called the FCI, initially developed by Hestenes et al. (1992), to assess students' conceptual understanding of mechanics. The FCI originated in North America and functions as a diagnostic evaluation tool across all levels of introductory physics education, ranging from high school to university. Although the FCI was originally developed in 1992, an updated edition with 30 items was created and made available online in 1995 (Halloun et al., 1995). This revised version was also included in Mazur's (1997) book. The original FCI had 29 items, and in the revised version, 1 item was added.

**Table 1.** Mann-Whitney U test results in a comparison of the experimental group with the control group's pre-test results

| | | Statistics | p |
|---|---|---|---|
| Newton's first law | Mann-Whitney U | 253 | 0.231 |
| Kinematics | Mann-Whitney U | 294 | 0.711 |
| Newton's second law | Mann-Whitney U | 252 | 0.188 |
| Newton's third law | Mann-Whitney U | 197 | 0.017 |
| Superposition principle | Mann-Whitney U | 277 | 0.453 |
| Kinds of force | Mann-Whitney U | 270 | 0.399 |

Later on, FCI was translated into many languages, and for the convenience of readers, all translations of FCI were collected, rectified, and published online (Hestenes & Jackson, 2007). FCI is a set of multiple-choice conceptual questions that cover six dimensions: kinematics, Newton's first law, Newton's second law, Newton's third law, superposition, and kinds of force. Each FCI question has five multiple-choice options with one correct answer, and each option addresses a taxonomy of commonsense misconceptions probed by the Inventory (Hestenes et al., 1992).

We chose this instrument because FCI is widely recognized as a tool to assess students' concepts and misconceptions about mechanics. It has been translated and validated in many languages worldwide, and it has previously been applied to the Kazakh population (Japashov et al., 2021). In the current work, we analyzed the reliability of the instrument using the KR-20 method (Oluwatayo, 2012), where the reliability coefficient for our sample was 0.7, meeting the accepted threshold of reliability.

Our sample consisted of native speakers of Kazakh and Russian with emerging proficiency in English. To accommodate this, we presented the FCI to students in three languages. The Russian version of FCI had already been translated from English and validated (Japashov et al., 2021). The authors carefully translated the FCI into the Kazakh language using cross-cultural translation procedures (Martín-Albo et al., 2007).

### Data Analysis

Parametric and non-parametric tests were employed to examine potential group-related differences in the student population. The Shapiro-Wilk test was applied to assess the normality of students' responses in all test results. Furthermore, the Mann-Whitney U test was used to investigate differences in pre-test results between the experimental and control groups. Only one dimension of the post-test was normally distributed, for which we applied an independent sample t-test, while other dimensions of the post-test were analyzed again using the Mann-Whitney U test.

During the analysis of students' pre-test results, it was discovered that the mean value of students' responses regarding the dimension of Newton's third law showed significant statistical differences. Therefore, for further analysis of this dimension, we utilized the ANCOVA test, enabling a comparison of the mean between two unequal groups. Since the data was not normally distributed, we decided to use a non-parametric ANCOVA test for this dimension.

## RESULTS

To assess the equality of students' conceptual knowledge in the experimental and control groups, we conducted an independent sample t-test for both groups' pre-test results. Before proceeding to the statistical analysis, the normality of the pre-test results for the experimental and control groups was checked.

The Shapiro-Wilk test indicated that all scores for the pre-test were non-normally distributed: kinematics ($W = 0.836$, $p < .001$), Newton's first law ($W = 0.936$, $p = 0.009$), second law ($W = 0.874$, $p < .001$), third law ($W = 0.940$, $p = 0.013$), superposition principle ($W = 0.899$, $p < .001$), and kinds of force ($W = 0.932$, $p = 0.007$). Since scores for the dimensions were non-normally distributed, we conducted the Mann-Whitney U test for all dimensions (see **Table 1**).

According to the Mann-Whitney U test scores, there is a significant difference only between the groups' responses regarding the dimension of Newton's third law ($p = 0.017$). The experimental group's mean values (mean [M] = 0.290, standard deviation [SD] = 0.213) are higher than the control group's mean values (M = 0.150, SD = 0.161). This suggests that both groups' conceptual understanding levels of mechanics are almost

**Table 2.** Independent sample t-test

| | | Statistics | df | p |
|---|---|---|---|---|
| Newton's first law | Student's t | 2.17 | 48 | 0.035 |

**Table 3.** Mann-Whitney U test results in a comparison of the experimental group with the control group's post-test results

| | | Statistics | p |
|---|---|---|---|
| Kinematics | Mann-Whitney U | 301 | 0.818 |
| Newton's second law | Mann-Whitney U | 167 | 0.003 |
| Superposition principle | Mann-Whitney U | 190 | 0.015 |
| Kinds of force | Mann-Whitney U | 209 | 0.039 |

**Table 4.** Non-parametric ANCOVA test results

| Source | Type III sum of squares | df | Mean square | F | Significance |
|---|---|---|---|---|---|
| Corrected model | 1,936.740[a] | 1 | 1,936.740 | 12.476 | < .001 |
| Intercept | .000 | 1 | .000 | .000 | 1.000 |
| PBL and non PBL | 1,936.740 | 1 | 1,936.740 | 12.476 | < .001 |
| Error | 7,451.129 | 48 | 155.232 | | |
| Total | 9,387.869 | 50 | | | |
| Corrected total | 9,387.869 | 49 | | | |

the same except for the dimension of Newton's third law. In terms of Newton's third law questions, experimental group students have a higher conceptual understanding than control group students. This difference will be considered in further analysis.

As a second step in the data analysis, we compared the two groups' post-test results to determine if there are any statistically significant differences in the groups' conceptual understanding of mechanics after the treatment.

The same procedure was applied to the post-test results. Firstly, we checked the normality of the distributed data by conducting the Shapiro-Wilk test. According to the results of the Shapiro-Wilk test, only the dimension of Newton's first law is normally distributed ($W = 0.959$, $p = 0.080$), while all other dimensions are non-normally distributed ($p < 0.05$). Therefore, we decided to conduct an independent sample t-test for the dimension of Newton's first law and the Mann-Whitney U test for the other dimensions. Considering that students' scores for the dimension of Newton's third law were initially unequal, we opted to conduct an ANCOVA test for this result. Since this data is not normal, we decided to conduct a non-parametric ANCOVA test. **Table 2** presents the results of the independent sample t-test for comparing the experimental group with the control group's post-test results.

In **Table 2**, we have presented an independent sample t-test for Newton's first law. As the results indicate, there is a significant difference ($t = 2.17$, $p = 0.035$) between the groups' post-test results. The mean values for the experimental group ($M = 0.584$, $SD = 0.288$) are higher than those for the control group ($M = 0.150$, $SD = 0.161$).

According to **Table 3**, after the experiment, only the dimension concerning kinematics shows no significant difference ($p = 0.818$), while all other dimensions exhibit statistically significant differences. To assess which group's conceptual understanding is better after treatment, we examined descriptive data. Concerning Newton's second law questions, the experimental group's mean value ($M = 0.560$, $SD = 0.315$) is higher than the mean value of the control group ($M = 0.280$, $SD = 0.299$). Similarly, for superposition principle questions, the experimental group's mean value ($M = 0.530$, $SD = 0.333$) is higher than the mean value of the control group ($M = 0.300$, $SD = 0.270$). Additionally, for the dimension regarding kinds of force, the experimental group's mean value ($M = 0.413$, $SD = 0.149$) was higher than the mean value of the control group ($M = 0.329$, $SD = 0.130$).

**Table 4** presents the results of the non-parametric ANCOVA test. Here, we also observe statistically significant differences between the groups' scores, with the experimental group's mean value being higher than the mean value of the control group. After analyzing the pre- and post-test, we conclude that PjBL positively affected our students' conceptual understanding of mechanics, particularly in terms of students'

**Table 5.** The goodness of fit analysis

| Items | Level | Count | Proportion | $\chi^2$ | df | p |
|---|---|---|---|---|---|---|
| 20th item | Pre-test | 4 | 0.182 | 8.91 | 1 | 0.003 |
| | Post-test | 18 | 0.818 | | | |
| 16th item | Pre-test | 3 | 0.158 | 8.89 | 1 | 0.003 |
| | Post-test | 16 | 0.842 | | | |
| 27th item | Pre-test | 6 | 0.273 | 4.55 | 1 | 0.033 |
| | Post-test | 16 | 0.727 | | | |
| 14th item | Pre-test | 2 | 0.0909 | 14.7 | 1 | < .001 |
| | Post-test | 20 | 0.9091 | | | |
| 18th item | Pre-test | 2 | 0.133 | 8.07 | 1 | 0.005 |
| | Post-test | 13 | 0.867 | | | |
| 19th item | Pre-test | 3 | 0.158 | 8.89 | 1 | 0.003 |
| | Post-test | 16 | 0.842 | | | |
| 9th item | Pre-test | 2 | 0.0952 | 13.8 | 1 | < .001 |
| | Post-test | 19 | 0.9048 | | | |
| 12th item | Pre-test | 10 | 0.833 | 5.33 | 1 | 0.021 |
| | Post-test | 2 | 0.167 | | | |
| 15th item | Pre-test | 2 | 0.182 | 4.45 | 1 | 0.035 |
| | Post-test | 9 | 0.818 | | | |
| 17th item | Pre-test | 3 | 0.136 | 11.6 | 1 | < .001 |
| | Post-test | 19 | 0.864 | | | |
| 3rd item | Pre-test | 2 | 0.125 | 9.00 | 1 | 0.003 |
| | Post-test | 14 | 0.875 | | | |

understanding of Newton's first law, Newton's second law, Newton's third law, the superposition principle, and kinds of forces.

Furthermore, for a deeper analysis to identify the specific items on which students could increase their scores, we conducted a chi-square test analysis of the results of the experimental group. In the goodness of fit analysis, it was hypothesized that correct scores on the pre- and post-tests are equal. Among all items, the differences between pre- and post-test scores of the 3rd, 9th, 12th, 14th, 15th, 16th, 27th, 17th, 18th, 19th, and 20th FCI items (Hestenes & Jackson, 2007) were statistically significant. To clarify, in **Table 5**, we have presented only the chi-square test results for these items.

**Table 5** represents 11 items with statistically significant differences. Among them, the scores of the experimental group for the 12th item significantly decreased after treatment, while scores for all other 10 items significantly increased in the post-test. The results of the goodness of fit analysis are consistent with other results except for item 12.

If we categorize the questions, we can see that the 20th item is related to kinematics, the 16th item is related to Newton's first law, the 27th item is related to Newton's second law, the 14th item is related to Newton's third law, and the 18th and 19th items are related to the superposition principle. Additionally, the 9th, 15th, 17th, and 3rd items are related to kinds of force. We observe that the 12th item, where students' scores of pre-test results are higher than post-test results, is related to the superposition principle.

The goodness of fit analysis showed that PjBL is highly effective in students' understanding of concepts related to the kind of forces.

## DISCUSSION

In conducting the current research, our aim was to examine the impact of PjBL on students' conceptual understanding of mechanics. After analyzing the pre- and post-test results, the t-tests and ANCOVA showed that PjBL positively affected our students' conceptual understanding of mechanics, specifically in terms of Newton's first law, Newton's second law, Newton's third law, superposition principle, and kinds of forces. The goodness of fit analysis demonstrated that PjBL is highly effective in enhancing students' understanding of concepts related to kinds of forces.

Despite the statistically significant differences in post-test results for all other dimensions, as mentioned in the previous chapter, there was no significant difference between the control and experimental groups in terms of the kinematics dimension of the FCI, according to the t-test. We explain this by noting that when it comes to the kinematics part, students in both groups were equally exposed to the basic concepts, and they could easily visualize and understand kinematic concepts encountered in everyday life (Lichtenberger et al., 2017).

However, concepts related to other aspects of mechanics demand more creativity and higher skills since their main principles are not readily observable (Japashov et al., 2024). For instance, forces like the traction force of a car's engine or the centrifugal force are not tangible and require theoretical and empirical assumptions for definition. In this context, the assistance of PjBL is crucial because real-life activities and strategies can facilitate students' understanding of these abstract concepts (Phanphech et al., 2019). Supporting this notion, Dahlan and Wibisono (2019) argue that hands-on activities structure students' knowledge and facilitate conceptual understanding. As indicated by the results of t-tests and ANCOVA, the use of a project-based approach significantly enhances students' grasp of concepts by actively engaging them in the learning process. Consequently, it is anticipated to foster the development of scientific understanding, including skills in designing, predicting, drawing conclusions, and forming hypotheses among the students (Balta et al., 2022; Pratiwi et al., 2019).

Another significant finding of our work is that the goodness of fit analysis demonstrated that PjBL is highly effective in enhancing students' understanding of concepts related to kinds of forces. We attribute this to the active use of lab equipment, such as a dynamometer and speedometer, by the experimental group to validate their statements obtained from hands-on projects. In explaining the nature of certain forces, students in the experimental groups first studied the theoretical assumptions, then simulated them in software, and finally verified them with the help of a dynamometer through mini projects. In contrast, students in the control group were limited to studying theoretical assumptions and computer simulations. We believe that the real-life modeling of situations and checking their operation with lab equipment strengthened the conceptual knowledge of the experimental groups' students about forces and facilitated longer retention (Berhitu et al., 2020; Karaçalli & Korur, 2014).

Overall, our findings align with the research of Martawijaya et al. (2023). Martawijaya et al. (2023) conducted a similar study with a pre-post-test design to assess the impact of the Ethno-STEM-PjBL model on students' conceptual understanding of physics. The authors found that the application of PjBL significantly increased students' conceptual understanding of physics and decreased the level of misconceptions. A noteworthy observation from our work, in line with Martawijaya et al. (2023), is the scarcity of literature on the direct effect of PjBL on mechanics concepts. Martawijaya et al. (2023) assert that empirical data about the direct relationship of PjBL to physics concepts such as mechanics, heat, electricity, and light are not well studied, and scholarly databases display only a few papers in corresponding fields.

## Limitations of the Study

The study has limitations concerning measurement tools and sample size. Regarding sample size, we couldn't incorporate a larger sample due to the necessity of isolating the instructor's teaching effect; thus, we confined our sample size to 50 students. Concerning tools, for a more comprehensive understanding of students' conceptual knowledge about mechanics, it would be more appropriate to employ a two- or three-tier test. This involves asking students about the reasons behind choosing specific multiple-choice answers after each question and then gauging their confidence levels (Aldazharova et al., 2024). This approach surpasses the use of a single-tier multiple-choice test.

Another significant limitation of the study is its straightforwardness. While we aimed to examine the effect of PjBL on students' conceptions of force, many other pedagogical aspects related to the implementation of PjBL remain unexplored. For example, we did not consider the impact of PjBL on students' intrinsic motivation toward learning physics–that is, we did not examine how PjBL may facilitate or enhance students' internal drive to engage with physics concepts (Meulenbroeks et al., 2024). Additionally, it would have been valuable to observe how students scaffold conceptual knowledge during their group work (Ferty et al., 2019).

Moreover, we believe that a more comprehensive study is needed to explore how students connect force concepts to culturally relevant practices (Krajcik et al., 2021). In particular, it would be beneficial to investigate how students recognize and incorporate elements of their everyday routines into their projects. Therefore, future research should explore these challenges to better support student learning within PjBL environments.

## CONCLUSION

The impact of PjBL on students' comprehension of broader physics concepts, such as mechanics, thermal physics, fluids, and Light, warrants deeper attention, as this field remains insufficiently researched. To contribute to the literature in this research area, we investigated the effect of PjBL on students' conceptual understanding of mechanics. In this study, experimental research with a pre- and post-test, utilizing experimental and control groups, was conducted with 50 ninth-grade students. Our findings revealed statistically significant differences between the pre- and post-test results of experimental and control group students in the following FCI dimensions: Newton's first law, Newton's second law, Newton's third law, the superposition principle, and kinds of forces. The goodness of fit analysis indicated that PjBL is highly effective in enhancing students' understanding of concepts related to kinds of forces. We believe that, throughout this one-semester study, we successfully ignited students' interest in physics and engineering. Students exhibited enthusiasm during the lessons and made diligent efforts to complete and defend their projects.

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**Declaration of interest:** The authors declared no competing interest.

**Data availability:** Data generated or analyzed during this study are available from the authors on request.

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