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Enhancing Students' Conceptual Understanding of Newton Law With Conceptual Problem Solving Learning: An Experimental Study

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Abstract: This study aims to examine the effectiveness of Conceptual Problem Solving-based learning in improving student conceptual understanding of Newtonian mechanics. The quasi-experimental method with a nonrandomized control group pretest-posttest design was used to compare students conceptual in the experimental and control class. The subjects in this study were 69 first-year students of the Physics Education study program at one of the state universities in Yogyakarta. Force Concept inventories are used to assess students conceptual understanding of Newtonian mechanics. The findings revealed that there was significant difference in the increase in students conceptual understanding between the experimental and control groups. The increase in conceptual mismatch in experimental class students using CPS learning was higher (N-gain = 0.33) compared to control class students using direct instruction learning (N-gain = 0.11), although both groups experienced an increase. This study provides a real picture that the CPS technique can be used as a more successful strategy to improve the quality of physics learning, especially in improving knowledge of basic topics that are often difficult for students to understand, one of which is Newton's Law.

INTRODUCTION

Conceptual understanding is interpreted as a basic ability that every student wants to achieve because it reflects the student's learning outcomes. However, what is meant is not just achieving grades (McDermott, 1991), because obtaining a high score does not necessarily represent a correct understanding of the concept. Good physics learning outcomes are reflected in good concept mastery (Sands, 2014). The ability to master physics concepts will also be closely related to students' ability to solve any problems in everyday life (Çepni et al., 2006). Students are considered to have mastered the concept if they are able to understand concepts that are considered essential in physics and are able to apply them to solve problems (Darmofal et al., 2002; Docktor et al., 2015; Kustusch, 2016) or to explain physical phenomena that occur naturally or through human engineering (Lin & Singh, 2011; NRC, 2012). One of the basic concepts of physics is Newton's law.

Newton's laws of motion are the primary principle in mechanics and serve as the conceptual foundation of for practically all other physics topics (Gates, 2014; Wilson, 2020). Although these laws underlie many principles of mechanics and everyday physical phenomena, students often have difficulty in understanding them in depth (Handhika et al., 2016; Mongan et al., 2020). Many students have only a superficial understanding of Newton's Laws and tend to memorize the formulas without truly understanding the underlying concepts (Hestenes et al., 1992). Research in physics education demonstrated many students' naive theory or misconceptions, even after the introduction of Newton's laws (Docktor & Mestre, 2014). Several learning approaches have been applied to teach Newton's laws (AlArabi et al., 2022; Jayanti, 2016; Mansyur et al., 2020; Savinainen et al., 2017; Smith & Wittmann, 2007; Suwasono et al., 2023). However, learning that combines the ability to grasp concepts with problem solving in a single learning experience is still unusual.

Traditional learning approaches that focus on direct instruction and problem-solving are not always effective in developing strong conceptual understanding. Traditional learning in this case the researcher means learning that has long been used as a substitute for learning, where the learning process carried out tends not to increase creativity and student interest in the learning process so that it is only a transfer of knowledge from the teacher to the recipient of information. Traditional learning methods often fail to improve students' deep understanding of basic physics concepts. This is because students are often unable to relate physics concepts to relevant real-world situations, resulting in low interest and motivation to learn physics (Redish, 2003). Therefore, learning interventions that focus on strengthening mastery of concepts in the problem-solving process are important.

The learning intervention in question is Conceptual Problem Solving (CPS)-based learning. Intervention is carried out to see how the influence of a CPS in changing or encouraging changes to the dependent variable of students, in this case the results of student learning for Newton's law material. Intervention in learning is an important part that must be provided by teachers in improving learning outcomes as well as to facilitate the achievement of learning objectives. Providing intervention in research can provide a new situation in influencing learning outcomes, but the results of the intervention produced in this study clearly provide a positive picture of the treatment given. The conceptual problem solving approach not only prioritizes and emphasizes the quantitative aspects of problem solving obtained from mathematical equations and procedures. However, it also emphasizes the qualitative analysis aspect of problem solving which includes selecting the right concepts and principles (conceptual understanding) (Docktor & Mestre, 2014). Several previous studies have confirmed the success of CPS learning in improving students' conceptual mastery.

Therefore, this study aims to explore the effectiveness of conceptual problem-solving-based learning in improving students' conceptual understanding of Newton's Laws. This study will use an experimental method in conducting a treatment to compare the learning outcomes of students who learn using conceptual problem-solving-based learning with direct learning which is sometimes always a concern for many researchers. This research is very important in the development of physics learning and from several analyzes there are still not many researchers found especially in the material of Newton's law. The results of this study are expected to provide a significant contribution to the development of more effective and relevant physics learning strategies to improve students' conceptual understanding.

METHOD

The research uses a quantitative approach in an effort to see how a treatment can change and also influence a certain condition which in this study is physics learning. This study utilized a quasi-experimental research method (Creswell, 2012). The experimental design used was a nonrandomized control group pretest-posttest design (Levy & J. Ellis, 2011). This design is suitable for evaluating the effectiveness of a program or learning intervention that is carried out, especially comparing 2 variables more clearly. The research design is shown in Figure 1.

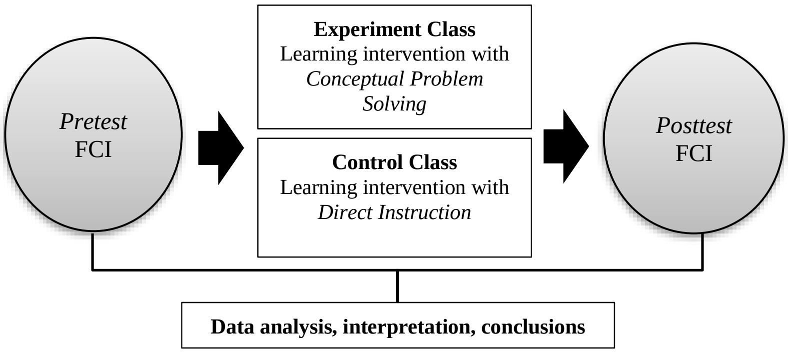

Figure 1. Research Design

The first step in quasi-experimental research is the implementation of a pretest to determine students' initial abilities on the topic of Newtonian mechanics using FCI. The pretest is administered before to the learning intervention. Following that, students get an intervention in the form of learning using a CPS approach. Then after the intervention, students are given posttest questions to determine changes in concept mastery. The pretest and posttest data are then analyzed to answer the research objectives. The last step is data interpretation and drawing conclusions. The study's subjects were students enrolled in the Physics Education study program at one of Yogyakarta's state universities. Participants were first-year students completing the Basic Mechanics course in 2023. A purposive sample technique was used to choose the research subjects. The study included 69 students, with 35 in the experimental class receiving a CPS learning intervention and 34 in the control class receiving direct teaching.

The Force Concept Inventory (FCI) is used to assess students conceptual understanding of Newtonian physics. FCI consists of 30 multiple-choice questions with 5 answer options. Each FCI item is related to one of Newton's laws. Among them, Newton's first law is represented by questions number 2, 6-10, 23, and 24, Newton's second law is represented by questions number 1, 3, 12, 14, 17, 19-22, and 25-27, while Newton's third law is represented by questions number 4, 5, 11, 13, 15, 16, 18, 28-30. The FCI instrument has been tested for validity through several studies (Coletta & Steinert, 2020; Munfaridah et al., 2017). Meanwhile, the reliability of FCI ranges from 0.81 to 0.9 (Munfaridah et al., 2017). The results of the reliability test indicate that the FCI instrument has consistency when used for testing. Thus, the FCI instrument can be used to analyze students' mastery of concepts in Newtonian mechanics topics. FCI can also be used to evaluate learning (Hestenes et al., 1992; Lee et al., 2017).

The data was evaluated with statistical descriptions to offer an overview of the central tendency, including the mean value, standard deviation, skewness, maximum and minimum values. In addition, descriptive statistics were used to see the increase in concept mastery which was marked by an increase from the average pretest to posttest scores of each student in the experimental and control classes. The difference in the average pretest and posttest scores of students' concept mastery was known from the paired sample t-test. Previously, a prerequisite test was carried out which included a normality test. The normality test was carried out by looking at the skewness results to determine whether the data collected was normally distributed or not. The results of the analysis were said to have a significant difference from the pretest and posttest scores when the significance value obtained was $p < 0.05$. Normalized gain (N-gain) analysis reveals how significant the increase in students' concept understanding is from pretest to posttest scores. The data from the N-gain analysis is utilized to calculate the average increase for each individual and the class average. Sutopo & Waldrip (2014) provide parameters for increasing N-gain. Furthermore, an independent sample t-test is used to determine the difference in average N-gain values between the experimental and control classes. Previously, an initial test was conducted, which comprised normality and homogeneity tests. The normality test examines the skewness results to determine if the collected data has a normal distribution or not. The homogeneity test is carried out using Levene's Test of Equity of Error Variance to assess whether or not the data is homogeneously distributed. The research found a significant difference in average N-gain values between the two classes ($p < 0.05$). The d-effect size value category is referred to Cohen et al. (2007).

RESULT AND DISCUSSION

The pretest and posttest scores of the experimental class with CPS learning and the control class with direct instruction learning provided data concerning students' conceptual understanding. To determine the effectiveness of learning in improving students' conceptual understanding of the Newtonian mechanics topics, data from the pretest and posttest were analyzed quantitatively using descriptive statistical methods, such as comparison of N-gain values, paired sample t-test, independent sample t-test, and d-Effect size. Table 1 shows descriptive statistics, which comprise N values, minimum, maximum, average, and standard deviation (SD).

The N-gain number is used to compare the increase in pretest and posttest scores between the experimental and control classes. Paired sample t-test is used to compare the average pretest-posttest scores of each class. Independent sample t-test is used to compare the average N-gain of two unpaired groups. The data generated either due to the treatment that has been used or without treatment obtained information or data obtained during the researcher, especially based on the results of the data analysis used, shows that there are differences, where the differences caused by the treatment used have a better or positive impact. d-Effect Size is used to determine the magnitude of the influence of the intervention given after the learning process. The Descriptive Statistics of the Experimental Class and Control Class Data can be seen in Table 1.

Table 1. Descriptive Statistics of Experimental and Control Class

	Experiment Class			Control Class		
Statistics	**Pretest**	**Posttest**	**N-gain**	**Pretest**	**Posttest**	**N-gain**
N	35	35	35	34	34	34
Minimum	3	9	0.18	0	2	0.04
Maximum	27	28	0.54	14	16	0.29
Mean	7.25	14.77	0.33	4.56	7.23	0.11
SD	4.12	3.51	0.08	2.88	3.31	0.07
Skewness	3.404	1.339	0.197	1.358	1.120	1.112

Table 1 shows that the average pretest to posttest scores increased in both classes. This means that students' conceptual mastery of the topic of Newtonian mechanics increased. In the experimental class, the average score of students' conceptual understanding increased from 7.25 to 14.77. In the control class, the average mastery score increased from 4.56 to 7.23. The increase in student learning outcomes in the experimental class can also be seen from the standard deviation where the standard deviation of the experimental class at the time of the pre-test was 4.12 while at the time of the post-test it was 3.51 which can be concluded that there is an indication of the average value of each individual student in the experimental class approaching the average value, so it can be ascertained that the treatment given is good and positive in influencing student learning outcomes, especially the material on Newton's laws. The diagram of the increase in pretest to posttest scores for both classes is shown in Figure 2.

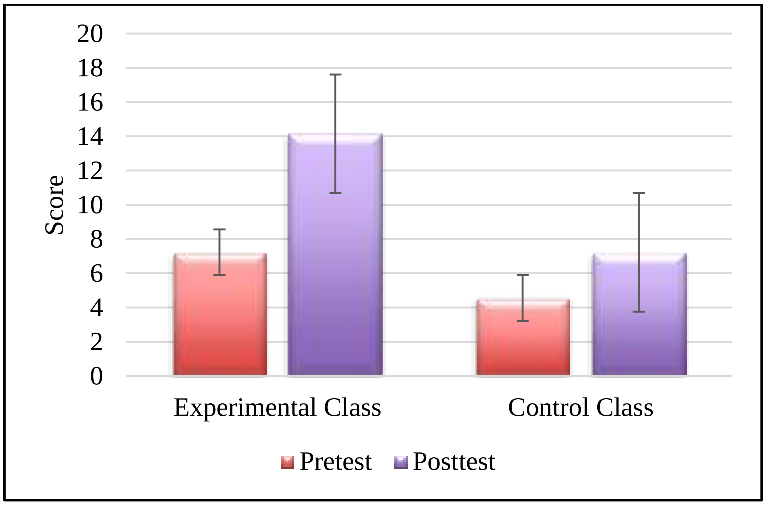

Figure 2. Diagram of the Increase in Pretest and Posttest Scores in Each Class

A paired sample t-test was carried out to determine the difference between the average pretest and posttest scores for students' conceptual understanding. The analytical results showed that the significant value in both the experimental and control classes was 0.000. This result is <0.05, indicating a significant difference in pretest and posttest scores for students learning through the CPS approach or direct instruction.

The normalized gain analysis (N-gain) shows the increase in students' pretest and posttest results in each class. The N-gain test is thought to correctly measure the effectiveness of a learning program (Coletta & Steinert, 2020). The experimental class's average N-gain value was 0.33, indicating a medium lower category. The control class had an average N-gain value of 0.11. This result falls into the low category. Based on these findings, it is possible to conclude that students in the experimental class with a medium low category improved their capacity to master concepts after receiving the CPS learning treatment for deepening Newtonian mechanics material. Meanwhile, the control class, which received direct instruction learning without any extra treatment, had a gain in concept understanding capacity, yet in the low category.

To test the average value of students' concept mastery in the experimental and control groups based on the average N-gain findings obtained, an independent sample t-test was used because it can compare 2 variables sharply. However, before conducting the t-test, the N-gain data from both classes were checked for normality and homogeneity. The normality test revealed that the N-gain data has a skewness score of 0.242. This number is between -1 and 1 indicating that the data has a normal distribution (Morgan et al., 2011). Furthermore, the results of the homogeneity test using Levene's Test of Equity of Error Variance revealed that the N-gain data for both classes had a value of 0.271. It implies that the N-gain data for both classes are homogeneously distributed. Thus, the independent sample t-test can be used to test the hypothesis about the difference in average N-gain between the experimental and control classes.

The independent sample t-test revealed a significant difference in N-gain values between the experimental class with CPS learning and the control class with direct instruction learning, with a p-value of <0.05. The results of the hypothesis test using the independent sample t-test were verified by the d-Effect Size calculation, which was used to measure the influence of the treatment. In the experimental class with CPS learning, a d-Effect value of $d = 1.971$ was achieved, demonstrating that CPS learning had a significant impact on future physics teacher students' understanding of Newtonian mechanics principles. This was slightly different from the d-effect results obtained by the control class of $d = 0.863$ with a high category. The results of the study clearly provide evidence that the treatment that the researcher used was able to provide a positive influence in influencing student learning outcomes or in other words, learning with direct learning was able to provide a high impact on increasing concept mastery.

Based on the results of the data analysis obtained above, it has provided evidence that learning with CPS is able to provide good effects and impacts on increasing students' conceptual mastery of the topic of Newtonian mechanics. These results are supported by several previous studies which state that students' conceptual mastery increases through learning with the CPS approach. Eda et al. (2021)in their research obtained a d-effect value of 1.69 (high) which shows that the practice of solving problems with the CPS approach has a strong impact on increasing students' conceptual understanding of the topic of thermodynamics. Meanwhile, in the study of Diyana et al. (2020) students' conceptual mastery increased significantly in the material on Archimedes' principle. Learning with

CPS in physics is also able to improve students' understanding and long-term concept retention and improve their problem-solving abilities (Mestre et al., 2011).

Analysis was also carried out through data filtering using the Publish or Perish application which researchers focused on data metadata from Google Scholar with the keyword Conceptual problem Solving, which researchers continued to describe using the VOSviewer application. Several research images on the relationship between conceptual learning and problems are the most widely analyzed relationships, but for conceptual problems researchers feel that there are still not many done, so it is still a very interesting study to do. The description of the relationship related to conceptual problem Solving can be seen in Figure 3.

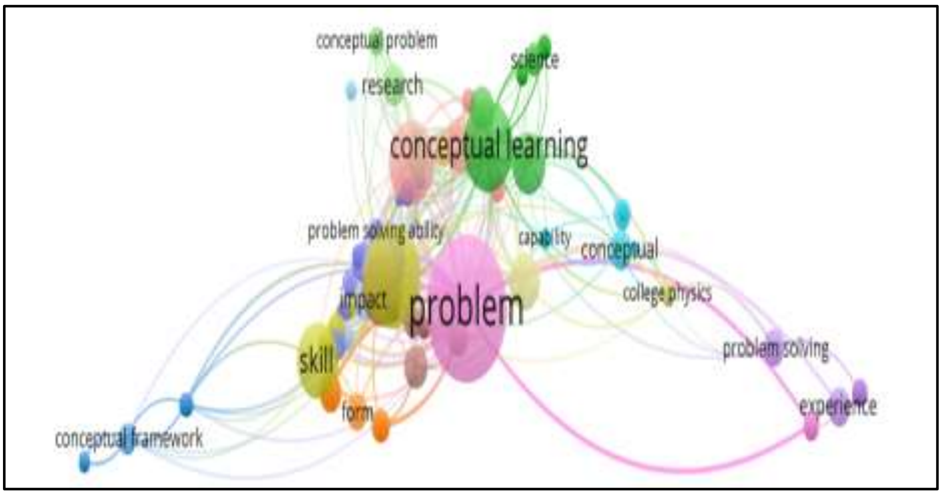

Figure 3. Network Visualization for Conceptual Problem Solving

The results of the analysis shown in Figure 3, clearly show that in physics learning, problem solving is associated with physics learning, while conceptual problems are still a very small part of the analysis, and at the same time indicate that it is still very important for this CPS to be analyzed in more depth. Conceptual Problem Solving (CPS) learning is a learning approach that guides students to identify problems (*identify principles*), explain the reasons for choosing the principle (*justify their use*), plan problem solving by writing the equations used and carrying out the planned steps (*plan their solution in writing before solving a problem*) (Docktor & Mestre, 2014). Conceptual problem solving is an important aspect in learning and applying physics understanding. Research shows that conceptual problem solving is enhanced by integrating conceptual and formal reasoning, following structured stages, and providing conceptual instructions before problem solving activities (Mestre et al., 2011). Emphasizing conceptual knowledge in problem solving, rather than just quantitative manipulation, will result in deeper understanding and better long-term retention.

Conceptual Problem Solving is an area that is still interesting and little research has been done, especially on Newton's laws. The analysis process of various data that has been collected by researchers also shows that the conceptual part of learning and problem solving is still an interesting study to analyze for the years 2000 to 2020. The description of research trends conducted by many studies, especially those discussing conceptual problem solving, can be seen in Figure 4.

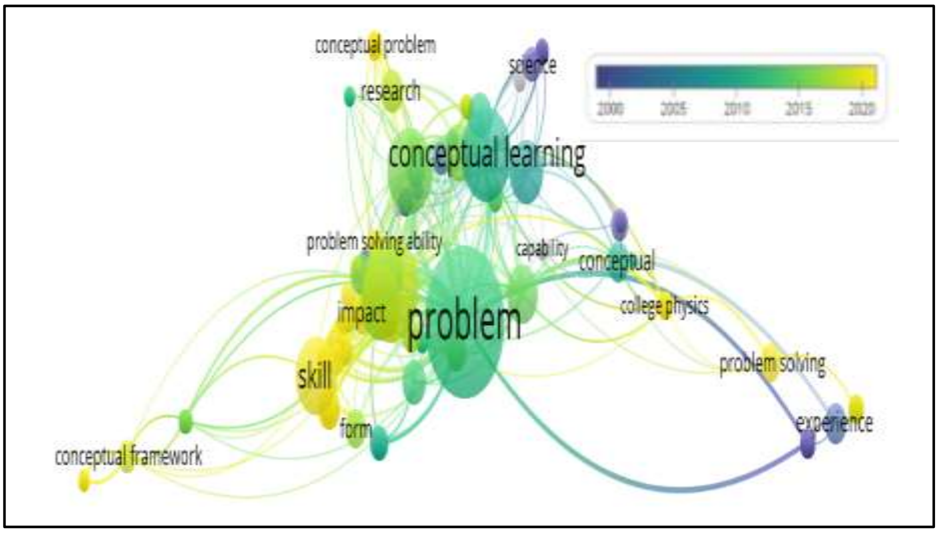

Figure 4. Overlay visualization for conceptual problem solving

The data analysis used by the researcher in Figure 4, clearly indicates that Conceptual Problem Solving is still an interesting topic and needs further investigation. The data also shows that in 2010-2015, the Problem indicator and conceptual learning were still separate parts and many still used them with their own understanding, then in 2020 conceptual problems and problem solving were studies that began to be analyzed even though they were still very few, which can be seen in Figure 5.

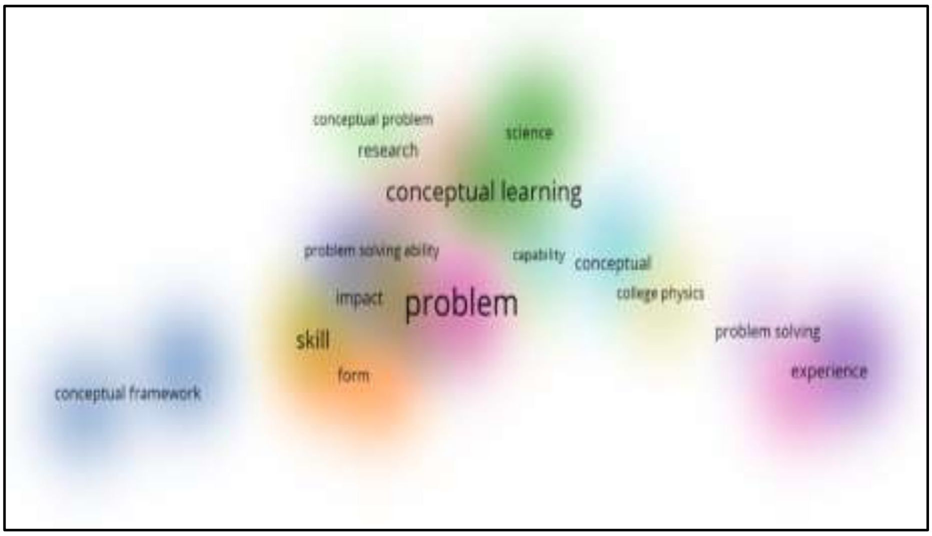

Figure 5. The Density visualization for conceptual problem solving

The process of describing an understanding and research trends provides a picture like picture 5 where there is a tendency for researchers to review conceptual problem understanding and problem solving is still not widely done. The data provided in figure 5 provides a fairly clear picture that the research conducted by the researcher is still very useful and is of particular concern in physics learning with the theme of Newton's laws.

Conceptual problem solving in this study clearly provides an indication as a solution that has a good and positive impact on the learning process. This study also shows that students in the control class with direct instruction learning experienced an increase in concept mastery even though it was in the low category. In addition, the direct instruction learning provided was also able to provide a high impact on increasing concept mastery when viewed from the d-effect size value. Although the increase was significantly different from the class with CPS learning. Several previous studies have shown that learning with direct instruction can also increase students' concept mastery on the topic of parabolic motion (Lestari & Mansyur, 2021) and mathematics (Tunde & Listiani, 2021).

CONCLUSION

This study revealed that CPS learning can help students gain a better conceptual understanding of Newtonian mechanics. There was a significant improvement in students' understanding of concepts before and after the learning intervention. The gain in conceptual knowledge of experimental class students with CPS learning was greater compared to the gain of control class students with direct instruction learning, but both increased equally. The findings show that CPS learning is more effective at improving student conceptual understanding than traditional direct instruction-based learning methodologies. This conclusion implies that the CPS technique can be utilized as a more successful strategy to increase the quality of physics learning, particularly in enhancing knowledge of basic topics that students frequently struggle to understand. It is recommended for research that will conduct data on other physics materials and also use additional data in describing research trends and relationships not only from Google Scholar student metadata but also from other metadata such as Scopus, CrossReff and so on that can support and provide a more comprehensive picture. The researcher also suggests that other researchers later use standard instruments as a tool in observing student abilities by first conducting logistic validity (asking for expert consideration) so that the questions used can be better and relevant to student abilities.

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