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Building Conceptual Understanding of Students on Laws of Newton through Argument-Driven Inquiry

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Abstract. Newton's law plays an important role in learning mechanics and explaining real-life phenomena, but students find it difficult to understand. This study aimed to build students' conceptual understanding and to describe students' difficulties with Newton's law after the Argument-Driven Inquiry (ADI) model learning process is implemented. This study used a quasi-experiment (pre-and post-test) design Pre- and Post-test design with the research subject of 50 tenth grade students in public high schools in Pamekasan, Indonesia. Students are distributed into the experimental class (ADI learning) and the control class (conventional learning). The instrument of this study was Newton's law understanding test in the form of reasoned multiple-choice questions with a reliability of 0.82. The research data were analyzed by the Mann-Whitney U test, ANCOVA, N-gain, d-effect, and a description of the reasons for students' answers. The results showed that conceptual understanding was not influenced by the initial state, but rather influenced by the ADI model. Improved conceptual understanding in the experimental class (medium category) is higher one level compared to the control class (low category). After the learning process, both classes students still have difficulty in the concept of a=F/m and its application, and objects in an inertial frame. However, the difficulties of the conventional class students are compounded by the friction, and Newton's I, II, and III laws concepts.

INTRODUCTION

Newton's laws have an important role in studying the concept of Physics (1) because it contains the concept of Force and Motion which is one of the basic concepts in Physics implemented in many phenomena relating to Physics in daily life (1,2). In the field of research, Newton's laws are one of the topics in Physics that become a focus in research about conceptual understanding (3). However, students still have difficulties understanding the topic of Newton's laws. Regarding Newton's first law, students still assume that gravity is the only force that's being experienced by an object and haven't realize the presence of normal force; on Newton's second law, students still assume that the non-zero net force will result in the object moving at a constant velocity; and on Newton's third law, some students assume that gravity and normal force is a pair in action and reaction forces (4). Other than that, students also experience difficulties in making a connection between net force, velocity, and acceleration in Newton's second law (5), determining the magnitude and direction of the acceleration of an object (6), and understanding $\sum \vec{F} = 0$, free body diagram, and action and reaction forces pair (7).

Previous research had been done to contribute to the conceptual understanding of Newton's laws. Some of the research are as follows. There is a significant number of students who still can't identify and draw all forces which act upon an object on physics representation worksheets (8). Students are still unable to implement the concept of Newton's laws to solve the problems in experiential learning (9). Students have understood the concept of Newton's laws with a multi-presentation approach, but there are still misconceptions of students about Newton's first, second,

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and third laws which are difficult to repair (10). Students still have problems with conceptual understanding, especially on the concept of inertia and forces in Newton's laws (11). These deficiencies in the research might be caused by the fact that students still hadn't been able to involve themselves in an active role in the whole process of learning so their understanding of Newton's laws is not optimized fully

Inquiry approach can facilitate a conducive environment so students have a chance to act on a more active role in learning, such as formulating several questions regarding the phenomenon or problem which is being discussed, applying themselves in an experiment in a laboratory to verify a theory which has been learned before, and representing or communicating their findings. The result of the research showed that the Inquiry Lesson with LBQ strategy was successful in improving students' conceptual understanding of Newton's laws (13). In other research, a class that was taught with a guided inquiry approach yielded better conceptual understanding with fewer misconceptions than a conventional class (14). The inquiry approach has the potential to increase students' conceptual understanding of the topic of Newton's laws.

One of the inquiry learning models which is considered suitable to increase students' conceptual understanding is Argument-Driven Inquiry (ADI) model. This is because ADI learning is an inquiry learning model based on laboratory, although students should've been more involved in scientific argumentation activity while working in teams on the experiment so their understanding of the important and practical concept can increase in the subject of Science (15,16). The activities of a scientific argument provide the facility to students to share and support students' ideas so it's ideal to increase communication and writing skills, construct their knowledge, and involve them directly to experience the process of how their knowledge is constructed or gained. ADI is distinct from other models in the sense that it gives students a chance to design their experiments and find the results on their own (16). The advantage of the ADI model lies in the process of investigation which guides students to design their experiments and to actively involve themselves to express their arguments (17). The step of identifying assignments about the topic which is going to be learned in the ADI model can inspire students to ask as many questions as possible so their conceptual understanding and mental model will improve (18). The activities in the ADI learning model emphasized knowledge construction and validation through experimentation so students are facilitated to understand the concept of Science well (19). The activities of the experiment in ADI class can help students understand how to make a scientific explanation, how to general scientific facts, how to use data to answer scientific questions, and how to reflect on their work which they had been labored on. ADI learning has big potential to help construct students' understanding of the topic of Newton's laws.

A conceptual understanding of Newton's laws can be constructed with the aid of the ADI approach. This study aimed to build students' understanding of Newton's laws with the ADI model which will be compared to the conventional model. Other than that, this research also aims to describe students' difficulties with Newton's laws after the process of the ADI learning model is implemented.

METHOD

This study used a quasi-experiment (pre-and post-test) design (20) with the research subject of 50 tenth-grade students in public high schools in Pamekasan, Indonesia. The research subjects were chosen with the cluster random sampling technique. Students are distributed into the experimental class (n = 23) and control class (n = 27). Students in the experimental class were taught with ADI learning, and the students in the control class were taught with conventional learning.

The activities of each class can be written in more detail as follows. ADI model had 8 syntaxes (21) to be implemented to construct 6 Bloom cognitive levels of conceptual understanding (22) of Newton's laws as written in Table 1.

TABLE 1. Syntaxes of Argument-Driven Inquiry to construct conceptual understanding

No	Syntax of ADI	Activity	Levels of Conceptual understanding
1	Identify the task and the guiding question	Students review and ask questions regarding the assignment about the phenomena in daily lives	Remember (C1)
2	Design a method and collect data	Based on the phenomenon, each team design a data-gathering technique in real-world and analyze the data by using an existing resource in daily lives	Understand (C2)

Continuation of Table 1.

TABLE 1. Syntaxes of Argument-Driven Inquiry to construct conceptual understanding

No	Syntax of ADI	Activity	Levels of Conceptual understanding
3	Analyze data and develop a tentative argument	Based on the phenomenon in daily lives, each student make an argument in the form of supporting and rejecting question and discuss them in the team so a systematical knowledge explanation will be formed	Apply (C3)
4	Argumentation session	Representatives of one team visit other teams to express their arguments and gain feedbacks for the arguments	Apply (C3)
5	Explicit and reflective discussion	The teacher and students discuss the findings of the experiment. Teacher gives further study assignment to develop students' thinking about the knowledge which they already learned and about new things to discover	Create (C6)
6	Write an investigation report	Students write individual reports based on the data and the findings of the experiment. The report contains hypotheses, purpose, methods, and arguments	Analyze (C4)
7	Double-blind group peer review	Evaluation by other same-grade students (peer review)	Evaluate (C5)
8	Revises and submits his or her report	Revision of the report after being evaluated by other same-grade student or peer review	Evaluate (C5)

It can be seen that students in experiment class had a chance to design the methods of data gathering, to construct arguments and discuss them with the team or with another team, to make report draft and discuss it with the team and with the class until it is transformed into more or less a complete report. The activity of each syntax in the ADI model is tailored to build a certain Bloom cognitive level. For example, the first syntax is designed to train the Remembering (C1) level and the sixth syntax is done to increase the level of Analyze (C4). Meanwhile, students in the control class are being treated with regular teachings, such as observing a certain phenomenon, working on a simple laboratory experiment, listening to the teacher's explanations to strengthen conceptual understanding, and practicing their knowledge on written problems and discuss them.

The instrument of this study was Newton's law understanding test in the form of reasoned multiple-choice questions. This test contains 13 test items that cover the concept of friction force and Newton's I, II, and III laws. Content validation was done to the test by a university lecturer and a teacher. Also, empirical validation was done towards 88 high school students which had learned the concept of Newton's laws. All these processes of instrument validation resulted in the alpha Cronbach reliability value of 0.82.

The research data were analyzed by the Mann-Whitney U test, ANCOVA, N-gain, d-effect, and a description of the reasons for students' answers. The pre-test data of the control class was not distributed normally, so the similarity test between the pre-test of both classes was done with Mann-Whitney U Test (23). Pre-test data of both classes were significantly different so the pre-test data was made as covariate variables to measure the difference between the post-test data of both classes using the ANCOVA test (24). The increase in students' conceptual understanding was analyzed with N-gain (25). The reasons which were stated in students' answers on the post-test distractor were analyzed to gain descriptions of students' difficulties on the topic of Newton's laws. An item will be considered as difficult if at least 20% of students choose the wrong answer on the multiple-choice question.

RESULT AND DISCUSSION

The average score and standard deviation of a pre-test for experiment and control class are, respectively, 23.44 (18.15) and 37.61 (11.36). It can be seen that the pre-test result of the experiment class is lower than the control class. The Kolmogorov-Smirnov normality test result of the pre-test data resulted in the value of Sig. 0.0001 (No Normal) for experiment class and Sig. 0.075 (Normal) for the control class. However, the homogeneity test of Levane statistics showed the result of Sig. 0.127 (Homogeneity). As there are data which is not normal, the similarity test for the initial state of students' conceptual understanding (pre-test) was done with a non-parametric statistic test with the Mann-Whitney test. The test yielded the result of Asymp. Sig. 0.000, which means that the pre-test of both classes was significantly different. This difference can affect the post-test result after the learning process. To remove this influence of this effect, the pre-test score of both classes was transformed into covariate variables.

The average score and standard deviation of the post-test score for experiment class and control class are, respectively, 55.00 (17.91) and 41.13 (13.35). It can be seen that the post-test result of the experiment class is higher than the control class. The test result of the Kolmogorov-Smirnov normality test for post-test data resulted in the value of Sig. 0.200 (Normal) for experiment class and Sig. 0.200 (Normal) for the control class. The result of the Levene Statistic homogeneity test showed the result of Sig. 0.165 (Homogeneity).

The requirement of the ANCOVA test compels that there is no interaction between the covariate variable and independent variable. The result of the prerequisite of the ANCOVA test is Sig. 0.994, which means that there is no interaction between the pre-test and the learning model. Therefore, the ANCOVA test can be done. The result of the Ancova is Sig. 0.098 (No Differences) for the initial-state of students' understanding. This can be interpreted that students' pre-test score didn't cause a difference in the post-test score. Another result of the ANCOVA test is Sig. 0.001 (Differences) for the models, so it can be said that different learning models on both classes caused the difference in the post-test score.

After the pre-test data has been transformed into covariate variable, we can see the mean and standard deviation of post-test data, which are 56.919 (3.391) for experiment class and 39.676 (3.103) for control class. This shows that the post-test score of both classes after the pre-test score was made a covariate variable is similar to the original pre-test score. It can be seen that the adjusted post-test score had a wider range than the original unadjusted post-test data. This reinforces the proof that the post-test score isn't affected by the pre-test score, but it's only influenced by the different learning models in both classes.

Students' conceptual understanding is only affected by the variations of the learning model. As the average score of the post-test of the experiment class was higher than the control class, it can be said that the ADI model can increase the understanding of Newton's laws significantly better than the conventional model. The process of the ADI learning model in Table 1 is indeed more complex than the conventional class. The syntaxes of ADI learning give students a chance to construct an understanding of Newton's laws better because students can design their experiments in the laboratory and formulate appropriate arguments to perfect their conceptual understanding. This result supports the findings in previous research that ADI learning can increase students' conceptual understanding (26).

The result of the N-gain of both classes can be seen in Table 2.

TABLE 2. The result of N-gain on each subtopic and the category

Classes	Friction force	Newton's I law	Newton's II law	Newton's III law	Total
Experiment	0.35 (M)	0.49 (M)	0.30 (M)	0.92 (H)	0.42 (M)
Control	0.38 (M)	- 0.37 (L)	0.10 (L)	- 0.05 (L)	0.06 (L)

Note: H = high, M = medium, and L = low

It can be seen from Table 2 that the subtopic of friction force has a similar gain on the medium category. However, on the subtopic of Newton's first and second law, the experiment class had a level higher gain than the control class. Further, on the subtopic of Newton's third law, the experiment class had a high category gain, which is two levels higher than the control class on the low category. Overall, ADI learning yielded a 0.42 value of N-gain in the medium category. This gain almost reached the threshold of average N-gain that can be found in active learning at a score of 0.48 (27). Meanwhile, conventional learning had N-gain with a value of 0.06 in the low category. This result supports the findings of previous research which stated that ADI learning can give a better impact than conventional class (28).

After the learning process is done, students still have some difficulties. These difficulties which are experienced by students in experiment and control class are summarised in Table 3.

TABLE 3. Summary of Wrong reasons for distractor in both classes

Number/Dimension/Indicator of Competence	Wrong reason for posttest distractor (%)
No. 4/C3/Apply Newton's I law on the problem of a car driver which suddenly hit the brake pedal on the moving car	Students assumed that the water bottle will stay still above the dashboard as the speed of the car undergoes a change (Exp = 20%), or the acceleration of the car is changing (Cont = 29.63%)

Continuation of Table 3.

TABLE 3. Summary of Wrong reasons for distractor in both classes

Number/Dimension/Indicator of Competence	Wrong reason for posttest distractor (%)
No. 6/C4/Comparing the magnitude of acceleration on the problem of two boxes which are placed on a smooth floor with the same force	Students assume that if the force is the same, then the acceleration of the object is proportional to the mass (Exp = 68%) Cont = 48.15%)
No. 7/C4/Comparing the force on the problem of a student which plays the ball in baseball, football, and basketball	If the acceleration is the same, students wrongly calculate the comparison of the force (Cont = 33.33%), or students assume that the force that is needed is inversely proportional to the mass, and wrongly calculate the comparison (Exp = 36%; Cont = 22.22%).
No. 8/C2/Determining the acceleration of a box which is being pushed	Students assume that the acceleration of the object is proportional to the mass and inversely proportional to the force (Exp = 36%), and wrongly calculate them (Cont = 25.93%)
No. 9/C2/Determining the connection of force, mass, and acceleration on the problem of Newton's II law	Students assume that in the case of pushing a box on an even surface, Newton's II law will apply, whose relation between force, mass, and acceleration is the net force of the forces acting upon an object which will always have an inverse proportion to the acceleration experienced by the object (Exp = 40%; Cont = 25.93%)
No. 11/C3/Applying Newton's II law on a certain circumstance	Students assume that some of the phenomenon containing the examples of the implementation of Newton's II law is the bus driver who suddenly puts his vehicle to a brake, in which the passengers' bodies are suddenly being propelled forward (Exp = 48%; Cont = 29.63%), and the hurt that is felt by the elbow when pushing the desk too hard (Exp = 20%), and the plane which seems as if doesn't experience movement when it flies on constant speed (Cont = 25.93%)
No. 13/C5/Summarising the velocity of an object which has fallen from a moving reference point with constant v, relative to another reference point	Students assume that an object which falls from a moving reference point with constant velocity relative to another reference point which is not in motion (fixed), the object is moving with zero velocity if seen from the point of view of the fixed reference point (Exp = 28%), or is moving with the velocity higher than 4 m/s (Exp = 20%; Cont = 29.63%), or is moving with the velocity less than 4 m/s (Exp = 28%)

From Table 3, it can be seen that after the learning process in both classes, students still have difficulty with objects in an inertial frame. Around 25% of students still hadn't understood that an object's movement on the non-inertial frame doesn't fulfill Newton's law (item number 4) and on the non-inertial frame (item number 13). This finding supports another finding on other research which stated that students assume that every moving object will always have a force acted upon it, even on the object which is moving straight with constant velocity (29). After the learning, students in both classes also still have difficulty with the concept of $a=F/m$. Around 55% of students are confused about the relation $a=F/m$ when F is the same (item number 6), around 30% of students are confused when the value of a is the same (item number 7), and around 30% of students are confused about the relations of $a=F/m$ itself (item number 8). Students also still have difficulty with the application of a=F/m. About the application of this equation, around 30% of students are still confused to understand the case of pushing a box on an even surface (item number 9), around 40% of students still had difficulty to understand the case of a bus driver who suddenly put his vehicle to a brake in which the passengers' bodies are suddenly being propelled forward, and around 20% of students are confused to understand the hurt that is felt by the elbow when pushing the desk too hard (item number 11). This finding supports the finding on other research which stated that on Newton's II law, students have difficulty to describe the magnitude (6,30) and the direction of the acceleration (6), to identify the net force and the definition of acceleration (31), and draw the connection between acceleration, net force, and velocity (5), and that force is proportional with the mass of an object (32). This shows that students still have difficulties in the conceptual understanding of the concept and applying Newton's laws. Students still have misconceptions and experience difficulties understanding force and motion (33-35). There is still indeed a misconception that is hard to change about Newton's I, II, and III laws (10). These difficulties happened because on the topic of force and motion, students didn't find it easy to make a mathematical and drawn representation (36-38), and they still have a low conceptual understanding (37,39,40).

Aside from the difficulties which were experienced equally as written in Table 3, students in the control class also experienced other difficulties which can be seen in Table 4.

TABLE 4. Summary of wrong reasons on distractor on the control class

Number/Dimension/Indicator of Competence	Wrong reason for posttest distractor (%)
No. 1/C1/Identifying the characteristic of friction force which acts upon a moving box on a slope	Students assume that the friction force on the moving object on a coarse slope does not depend on the coarseness of the surface (Cont = 33.33%)
No. 3/C2/Explaining Newton's I law on a moving object	Students assume that if a table is being pushed so it has a constant velocity v, the magnitude of the net force depends on the mass (Cont = 25,93%) or the magnitude of v (Cont = 40.74%)
No. 10/C3/Determining the force which is needed to put a snow sled into acceleration without friction	Students assume that the horizontal surface of ice without friction can decrease the magnitude of force which acts upon a mass m and with an acceleration a (Cont = 29.63%)
No. 12/C2/Determining the winning team on the application of Newton's III law on the tug-of-war game	Students assume that on the game of tug-and-war, the B team gives force toward A team, but A team doesn't give force toward the B team (Cont = 48.15%)

However, the difficulties of the students in the conventional class are compounded by the friction, and Newton's I, II, and III laws concepts. On any surface, friction depends on the level of the surface's coarseness and normal force. The normal force depends on the mass, gravitational acceleration, and tilt of the object. However, around 33.33% of students think that the friction force does not depend on the coarseness of the surface. It seems that students still feel the abstract nature of the relation of friction force, the mass of an object, and gravity (41). On a still or moving object with constant speed, net force doesn't apply. However, in this case, students still consider that the magnitude of the force is not constant, but changes because of mass (25.93%) or because of the magnitude of v (40.74%). It's apparent that in the case of a still or moving object with constant velocity, students often still haven't applied Newton's First law about inertia (42). On the moving object on the ice surface, it can be assumed that there is no friction force. However, in this case, as much as 29.63% of students still think that the friction force applies so the net force is reduced. It's clear that students still haven't understood the physical meaning of Newton's laws so they can only recall the laws by words and nothing more (43). On the interaction of two objects, if the first object applies a force on the second object, then the second object also applies a force on the first object with the same magnitude but toward the opposite direction. However, as much as 48.15% of students still assume that the force is done only by an object. It's apparent that on conceptual understanding the pairing of action and reaction forces on Newton's III law, students still have difficulty in identifying all forces acting upon the object and draw those forces on the free-body diagram (7).

CONCLUSION

Based on the result and discussion, it can be concluded that the pre-test data of the control class (37.61) was higher than the experiment class (23.44), but the understanding of the topic of Newton's Law was not influenced by the initial state (pre-test). The average score of the experiment class (55.00) was significantly higher than the average score of the control class (41.31) so the ADI model affects the understanding of Newton's laws. The increase of conceptual understanding in the experimental class, which is represented by the N-gain value of 0.42 (medium category), is one level higher than the N-gain in the control class with the value of 0.06 (low category). After the learning process, students of both classes still have difficulty in the concept of a=F/m and its application, and objects in an inertial frame. However, the difficulties experienced by students in the conventional class are compounded by the friction, and Newton's I, II, and III laws concepts. It is recommended for future research to integrate the STEM approach and formative assessment into the ADI model so that the learning process can be optimized to reduce students' difficulties significantly.

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