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Exploration of Students' Scientific Argumentation Ability through an Argument-Driven Inquiry Approach in Newton's Law Learning

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Abstract

Scientific argumentation is an essential skill in science education, particularly in understanding Newton's Laws, as it enables students to construct claims supported by evidence and logical reasoning based on real-world phenomena. However, many students struggle to produce complete and structured arguments. This study aims to explore students' scientific argumentation skills through the Argument-Driven Inquiry (ADI) model, focusing on Grade X MIA 1 students at SMAS Kawung 2 Surabaya. Using a mixed-methods approach with an explanatory sequential design, the study involved 20 students in an experimental class. Data were collected through pre-tests and post-tests consisting of the same three essay questions, and interviews were conducted to assess deeper development in argumentation. Quantitative data were analyzed using descriptive statistics, including normality tests, paired t-tests, n-gain, and effect size calculations. Qualitative data from interviews were analyzed narratively, using data reduction and coding based on Toulmin's Argumentation Pattern (TAP), and responses were classified into five levels (1–5). Results revealed an improvement in students' argumentation levels. For question 1, students progressed from level 2 to level 3, with some reaching level 4. For question 2, the increase was from level 1 to level 2, with a few achieving levels 3 and 4. The N-gain score of 0.35 (moderate) and an effect size of 2.46 (strong) indicate a significant positive impact of the ADI approach. The findings suggest that ADI can effectively enhance students' scientific argumentation skills and may serve as a promising strategy for educators to integrate into argumentation-based learning modules.

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INTRODUCTION

Newton's Laws are fundamental concepts in physics that explain the relationship between force, mass, and the motion of objects. These three laws—Law I (inertia), Law II (the relationship between force, mass, and acceleration), and Law III (action-reaction)—form the basis for understanding various classical mechanical phenomena. Although fundamental, the concepts in Newton's Laws are often difficult for students to understand because they are abstract and require strong cause-and-effect reasoning skills (Fitriani et al., 2021; Nurhasanah et al., 2022; Prasetyo & Suryani, 2023). This difficulty indicates the need for a learning approach that emphasizes not only memorization but also encourages students to explain concepts through argumentation.

In science learning, scientific argumentation skills are one of the key skills that need to be developed. Scientific argumentation involves formulating claims, supporting them with empirical evidence, and connecting them through logical reasoning (Osborne & Dillon, 2020). This skill not only helps students understand concepts in depth but also trains them to communicate ideas rationally and critically, a very important skill in both academic and professional life (Sampson et al., 2019).

One effective approach to developing this ability is Argument-Driven Inquiry (ADI). ADI is an inquiry-based approach that places students as active participants in the scientific process, from formulating questions to designing and conducting experiments, analyzing data, and building arguments based on evidence through group discussions (Misbah, Hamidah, Sriyati, & Samsudin, 2024; Misbah, Hamidah, Sriyati, Samsudin, & Rahman, 2024; Rahayu et al., 2020; Walker & Sampson, 2019). In the context of learning Newton's Laws, ADI allows students to test concepts such as Newton's Second Law (F = ma) through simple experiments, then formulate arguments based on observations and data (Andriani et al., 2023). Thus, this approach has the potential to not only improve students' understanding of physics concepts but also train critical and argumentative thinking skills in a structured manner (Pratiwi et al., 2022).

Despite its great potential, implementing ADI in learning comes with challenges. Time constraints, limited laboratory facilities, and teachers' readiness to facilitate scientific discussions are among the main obstacles (Wulandari et al., 2023). Additionally, students who are unfamiliar with the inquiry approach often struggle to construct complex arguments, particularly in logically connecting data to theory (Nugraha et al., 2021). This is especially evident in the context of Newton's Laws, where most students reach only Level 2 of scientific argumentation—making claims based on data but often grounded in misconceptions about Newton's Laws (Amir et al., 2020). Furthermore, students still find it difficult to develop arguments based on both data and theory in physics learning (Ropika et al., 2019). The ADI approach has emerged as an alternative to enhance students' argumentation skills. The ADI process requires students to conduct investigations through open-ended experiments, interpret data, develop written scientific arguments, and defend their arguments in group discussions (Hidayat et al., 2022; Sari et al., 2023).

Widayanti's (2017) study employed a multi-representation approach to assess students' conceptual understanding and scientific argumentation related to heat. However, the study had certain limitations. Its exclusive focus on heat reduced the generalizability of its findings to other, more abstract areas of physics, such as dynamics. In addition, the analysis of argumentation was not conducted in depth, as it relied primarily on quantitative data and did not systematically examine the components of the Toulmin Argumentation Pattern (TAP). In light of these limitations, the present study was designed to implement the ADI model on Newton's Laws and to conduct a more comprehensive analysis of students' argumentation using the TAP framework. This also aims to broaden the application of the multi-representation approach to more complex subject matter.

Given the importance of argumentation skills in physics learning, especially in Newton's Laws, the ADI approach is relevant for further study. Through an inquiry process that emphasizes claim formulation, data analysis, and the defense of evidence-based arguments, this approach can improve students' conceptual understanding and critical thinking skills. Research by Hidayat et al. (2022) shows that consistent application of ADI can improve the quality of students' scientific arguments, especially in linking empirical data to underlying physics principles. In addition, arguments developed through group discussions have been shown to strengthen conceptual understanding and encourage reflective thinking (Sari et al., 2023). Therefore, this study aims to explore students' scientific argumentation skills through the ADI approach.

METHODS

The method used in this study is a mixed-methods approach to fully explore the research subject, with an explanatory sequential design (Ivankova et al., 2007). This research design allows for first collecting quantitative data and then collecting qualitative data to help explain the results of the quantitative data (Creswell & Creswell, 2023).

The first step in this study was to collect quantitative data and analyze it. Quantitative data collection was carried out using a one-group pre-test and post-test design (Creswell, 2015). The subjects of this study were 20 students of class X MIA at SMAS 2 Kawung Surabaya on Newton's Law material. Data collection began by giving a pre-test consisting of 3 argumentative essay questions. The next activity was learning Newton's Law material using ADI and concluded with a post-test containing the same questions as the pre-test. The test results were used to measure students' scientific argumentation skills and describe them. The test results are grouped at each level, which is used as a guideline for scoring students' scientific argumentation skills. Scoring is done to facilitate the analysis of students' argumentation skills at each level. The analysis technique used is descriptive statistics, which includes normality tests, paired t-tests, n-gain with categorization based on Hake (1998), and effect size with categorization based on Cohen et al. (2007). Based on the quantitative analysis results, interview respondents were randomly selected using the simple random sampling technique.

The second step is to collect qualitative data and analyze it. Data collection by conducting semi-structured interviews to explore students' argumentation skills on two questions and students' perceptions of Newton's Law through ADI learning. Data analysis is carried out with the stages of data reduction, data coding, data presentation, and interpretation (Creswell, 2015). The quantitative analysis results, supported by the qualitative analysis, are then interpreted and presented descriptively.

RESULTS AND DISCUSSION

The data on scientific argumentation ability achievement criteria were analyzed based on the answers and adjusted to the argumentation scoring guidelines. Argumentation scoring is based on the TAP criteria developed by Erduran et al. (2004) in the form of levels, namely level 1, level 2, level 3, level 4, and level 5. The scoring criteria were modified to make it easier to sort scientific argumentation criteria, as in Table 1.

Table 1 TAP argumentation level sequence

Level	Argumentation Scoring Criteria
Level 5	Argumentation consisting of claims accompanied by data, warrants, and backed with more than one rebuttal
Level 4	Argumentation consisting of claims accompanied by data, warrants, and backing
Level 3	Arguments with a series of claims accompanied by data and warrants
Level 2	Argumentation consisting of claims with data
Level 1	Argumentation consisting of simple claims
Level 0	Not identified, students do not answer or respond

The grouping of the scientific argumentation criteria from the pre-test and post-test in question 1 is shown in Figure 1.

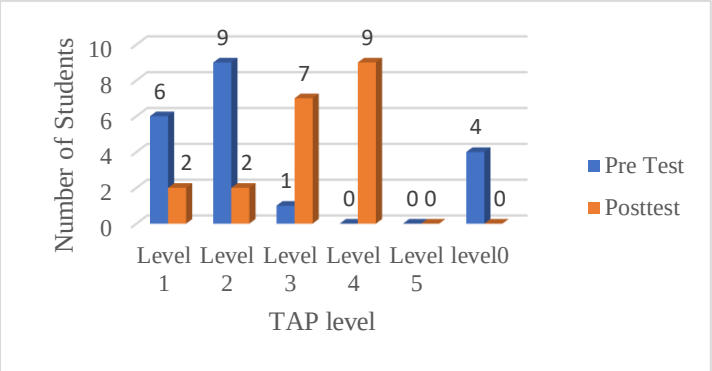

Figure 1 Grouping of argumentation criteria for question number 1

Figure 1 shows that before ADI learning was implemented, 30% of students were at level 1, 45% at level 2, 5% at level 3, and 20% at level 0. The data show that students' scientific argumentation ability remains low, as evidenced by the large number at level 2. Good arguments must be based on adequate conceptual knowledge (Chen et al., 2013). The ability to argue must be supported by conceptual knowledge. Students' conceptual knowledge can be developed through meaningful learning that allows them to build concepts, especially Newton's Laws.

Students' scientific argumentation ability is analyzed from their responses during the pre-test and post-test. Analysis of students' answers during the pre-test, as shown in Figure 2, indicates that it is better to hold the hammer with the handle down rather than with the hammerhead down.

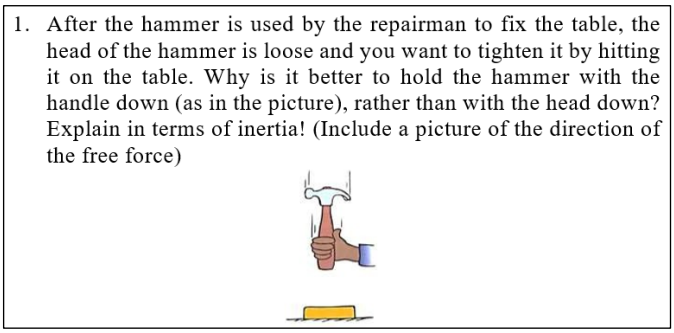

Figure 2 Argumentation Test Instrument 1

Students are directed to analyze the tendency of objects to maintain their initial state, i.e., the resultant force is equal to zero. Before ADI-based learning, students' arguments remained limited to intuitive understanding, lacking strong scientific justification. Many students gave arguments related to question number 1 (see Figure 2) that holding a hammer with the handle down can cause the hammer head to tighten; when the bottom is hit, the hammer will maintain its position. This argument has led to the concept of inertia, but has not explicitly explained the relationship between force, action-reaction, and inertia in the event.

Before ADI-based learning, students' arguments remained limited to intuitive understanding, lacking strong scientific justification. Student A gave an argument related to question number 1: "*Because holding the hammer with the handle down can cause the hammerhead to tighten, when the bottom is hit, the hammerhead will maintain its position*." This argument has led to the concept of inertia, but has not explicitly explained the relationship between force, action-reaction, and inertia in the event.

After the ADI learning, students' argumentation improved. Student A then added, "*The hammerhead that maintains its position will resist the upward reaction force (moving down), causing the hammerhead to be tighter. If the hammerhead is hit, it will become looser."* In this argument, students began to use Newton's First Law more effectively and

to relate it to experimental evidence. In addition, students were able to describe the direction of force and explain the external forces that influence the object's state, indicating that students' argumentation has reached level 3 TAP, namely claims with sufficient evidence and clearer warrants.

Another student argued, "*If we hold the hammer with the handle down as in the picture and then hit the end of the handle on the table, then because of inertia, the loose hammerhead will want to stay still when the bottom of the hammer suddenly stops. As a result, the hammerhead is pushed down and becomes tighter. But if the hammer head is down and we hit the hammer head on the table, then the entire hammer moves together, and the hammer head will not be pushed into the handle."* This argument shows that the student's argumentation has reached level 4 TAP because it demonstrates a deep, structured understanding of scientific concepts, is supported by the appropriate theory, and distinguishes two physical situations using logical reasoning based on concepts (Marsiah et al., 2022).

The results of an interview between a teacher and one of the students reflecting the student's scientific argumentative ability regarding question number 1:

Teacher: "Why do you think the hammerhead can go back in if the bottom is hit against the table?"

Student A: "Because when it is hit, the bottom stops because of the table, but the hammerhead still wants to stay. So relatively, the hammerhead seems to move down and is pushed in."

Teacher: "Good. What is the physics term that explains this?"

Student A: "Inertia, ma'am. Because the hammerhead does not immediately change its movement."

Meanwhile, the grouping of the scientific argumentation criteria from the pre-test and post-test in question 2 is shown in Figure 3.

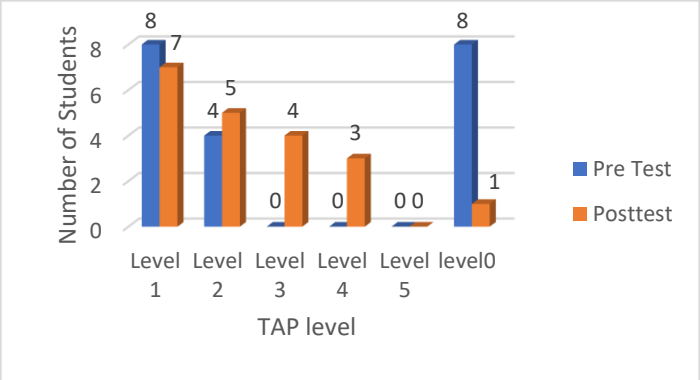

Figure 3 Grouping of argumentation criteria for question number 2

In Figure 3, it can be seen that before ADI learning was implemented, 40% of students were at level 1, 20% at level 2, and 40% at level 0. The data show that students' scientific argumentation ability remains low, as evidenced by the large number of students at level 1, and none have reached levels 3 to 5. Analysis of students' answers during the pre-test, as in Figure 4, tests students' understanding of Newton's Third Law (Action-Reaction) through the phenomenon of force interaction in everyday life.

2. If we walk forward on a raft floating in water, the raft will move backward. Why is that? Relate this phenomenon to Newton's Third Law! (Include a picture of the direction of the free force)

Figure 4 Argumentation test instrument 2

The question indicator in Figure 4 analyzes Newton's Third Law: if someone exerts an action force on an object, the object will exert a reaction force (equal in magnitude but in the opposite direction). Before learning ADI, students argued that "*Because humans give a pushing force to the raft, the raft reacts by moving backward."* This argument has led to the principle of action-reaction, but it lacks a conceptual explanation of the relationship between the action and reaction forces.

Problem stimulation is carried out through ADI-based learning. In the exploration phase of the phenomenon, students are given problems such as "*If we walk forward on a raft floating in water, the raft will move backward. Why is that? Relate this phenomenon to Newton's Law."* This question is used to stimulate students' critical thinking and scientific argumentation skills in the context of classical mechanics, especially the application of Newton's Third Law of action and reaction. The argumentation process is developed through the ADI approach, where students are asked to make claims, support them with evidence, and explain them with relevant scientific reasoning. The following is an excerpt from an interview between a teacher and a student that reflects the student's scientific argumentative abilities.

Teacher: “When someone walks on a raft and the raft moves backward, why do you think that happens?”

Student : “Because when the person walks forward, he gives a backward push to the raft. Therefore, the raft will be pushed backward.”

Teacher: “Good. Try to explain it with the laws of physics that you know.”

Student : "That is in accordance with Newton's Third Law. Every action has an equal and opposite reaction. When our feet push the raft back so we can step forward, the raft will exert a forward reaction force on our body. But because we are on the raft, what appears is that the raft is moving backward."

Teacher: “So you conclude that the action force comes from...?”

Student: “The action force comes from the push of the feet to the raft, and the reaction force is from the raft to our body. Because we are standing on the raft, our movement makes the raft push backward.”

Teacher: “Good. If there is no friction between the feet and the raft, will the same phenomenon occur?”

Student: “No. If there is no friction, the feet cannot push the raft. So, there will be no action and reaction forces, so there will be no movement.

After learning ADI, students' arguments improved. Student B then added, "*If someone applies an action force to an object, the object applies an equal but opposite force back. The raft going backward when a person walks is a reaction force due to the action force that a person applies."* This argument shows that students have better understood Newton's Third Law and can apply it to everyday problems. In addition, students began to construct arguments with a more complete structure, including claims, evidence from experiments,

and logical scientific explanations, indicating an increase to level 4 TAP: claims with strong evidence, warrants, and backing. This indicates that the ADI model not only improves students' conceptual understanding but also helps them construct more structured and critical arguments. Eliana & Admoko (2020) also support the claim that applying Toulmin's Argumentation Pattern in physics learning can help students develop a more systematic, evidence-based argument structure.

The interview results showed that students' difficulties stemmed from shortcomings in answering questions and in understanding the material. The weakness is explaining the material that is clearly difficult for students to understand. When students have difficulty understanding the material, they also struggle to express scientific arguments—applying the ADI learning model to the context of teaching and learning everyday life phenomena and analyzing them in the classroom using Newton's Law material. Students learn through personal experience and build the structure of Newton's Law theory. Contextual learning can enhance students' ability to argue, as evidenced by increased performance. Many additional models are used, namely diagrams, photos, natural phenomena, tables, and videos.

Scientific argumentation is the process by which individuals put forward claims supported by evidence and logical reasons. In the context of science, this ability is very important because it allows students to understand and critically evaluate scientific concepts (Melta et al., 2024). Research shows that applying learning models that emphasize scientific argumentation, such as ADI, can improve students' critical thinking and problem-solving skills (Nur et al., 2022).

Overall, the post-test score increases after the ADI model is applied. In this study, the increase in students' scientific argumentation abilities was measured using two parameters, namely d-effect size and N-Gain. The following presents descriptive statistical data on scientific argumentation in Table 2.

Table 2 Descriptive statistical data of scientific argumentation

Category	N	Min	Max	Mean	Median	Std.Dev
Pre-test	20	1.00	5.00	3.1	3.00	1.293
Post-test	20	3.00	11.00	7.3	7.00	2.028

Based on the data in Table 2, the average value increased from 3.1 in the pre-test to 7.3 in the post-test. Based on these data, there was an increase after being given treatment in the form of ADI learning. This increase is evident in the average post-test value, which increased by 4.2%. The highest value obtained during the pre-test was 5 out of 15. While the highest post-test value was 11, the results increased after treatment. This indicates that the number of students with the best understanding is increasing. Furthermore, a prerequisite test was carried out: a normality test to determine whether the data were normally distributed so that they could represent all samples.

To test the effectiveness of ADI learning in improving students' abilities, a Paired Samples t-test was conducted as shown in Table 3.

Table 3 Paired sample test results

	Paired Differences				
***Pretest*_AI *Posttest*_AI**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t**	**Sig. (2-tailed)**
	-4.20	1.935	0.432	-9.703	0.000

The test results show a t value (df = 20) = -9.703, and the significance result obtained is 0.000, so it can be said that there is a significant difference in students' argumentation abilities before and after being given ADI-based learning because the requirements for the

paired samples test are: sig <0.05. This shows that ADI-based learning significantly improves students' argumentation abilities.

The improvement in students' scientific argumentation ability was measured using two parameters: N-Gain and effect size. The N-Gain test was conducted to determine the extent of improvement in students' problem-solving ability. Table 4 shows the N-Gain test results.

Table 4 N-Gain test results

Pre-test Average	Post-test Average	N-Gain	Category
3.1	7.3	0.35	Medium

Based on the data in Table 4, the average N-Gain result was 0.35, which is in the moderate category. This shows that students' argumentation ability has increased in the moderate category. From these results, it can be said that ADI-based learning has a significant positive impact on students' scientific argumentation ability on Newton's Law. The Effect Size test is used to determine the extent of ADI learning's influence. The following are the results of the effect size test in Table 5.

Table 5 Effect size test results

Mean (*Posttest-Pretest*)	Std. Deviation	Effect Size
4.2	1.70	2.46

Based on the results of the effect size test, which determined the extent of ADI learning's influence on students' argumentation skills, the effect size was 2.46, placing it in the strong category (Cohen, 2013). This means that the ADI learning given to students is effective in improving students' argumentation skills in Newton's Law material.

One aspect that showed significant improvement was the students' ability to provide rebuttals. While in the pre-test, students tended to present only claims without considering alternative viewpoints, in the post-test, they began to offer more critical, evidence-based rebuttals. This indicates that ADI learning not only enhances students' ability to construct arguments but also trains them to evaluate and critique others' arguments scientifically.

In its implementation, teachers or researchers need to develop a well-prepared instructional design and allocate sufficient time for discussing and exploring students' ideas. A larger sample size, along with the use of a control group, is also necessary to ensure greater validity and allow the findings to be generalized to a broader population.

CONCLUSION

Based on the results of the data analysis and discussion, it can be concluded that students' argumentation ability in learning Newton's Law material through the ADI model has increased significantly. The ADI model helps students develop evidence-based arguments, think critically, and understand physics concepts more deeply. This is evidenced by the analysis results, which show that students who previously made only claims without evidence developed the ability to include data, warrants, backing, and rebuttals. In addition, the N-gain value of 0.35, which is included in the moderate category, and the D-effect size value of 2.46, which is included in the strong category, indicate an increase in understanding in building more structured scientific arguments. Thus, the ADI model has proven effective in improving students' argumentation ability on Newton's Law material. Based on the analysis of scientific argumentation ability and discussion, schools should rethink their learning methods to improve students' argumentation skills in Newton's Law material. For teachers, it is better to know students' weaknesses in mastering physics concepts before holding an oral test on students' scientific argumentation ability.

Further research is recommended using a larger sample to increase the validity of the findings and allow generalization to a broader population. It is also advised that future

studies include a control class for comparison, so that the effectiveness of the ADI model can be evaluated more objectively. Educators are encouraged to systematically implement the ADI learning model across teaching and learning activities, especially for concept-heavy topics such as Newton's Laws. This model has been proven to enhance student engagement in scientific thinking processes and to strengthen conceptual understanding. In its implementation, teachers should carefully prepare their lesson plans and allocate sufficient time for discussion and exploration of students' ideas.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

HO contributed to the conceptualization, methodology, investigation, product pilot testing, instrument design, and preparation of the final draft. LY participated in validation, consultation on data analysis, and report writing, while EL provided consultation on the literature review and references.

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