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EVALUATING STUDENTS' ARGUMENTATION SKILLS USING AN ARGUMENT-GENERATING LEARNING MODEL SUPPORTED TOULMIN'S ARGUMENTATION PATTERN IN PHYSICS CONCEPTS

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ABSTRACT

This study examines the effectiveness of the Argument-Generating (AG) learning model, supported by Toulmin's Argumentation Pattern, in enhancing students' argumentation skills with a specific focus on physics. The primary aim is to evaluate how the AG learning model, augmented by Toulmin's framework, improves students' abilities to construct and defend arguments in the context of physics. Additionally, the research seeks to assess the overall effectiveness of this instructional approach and gather student responses regarding its application. A quasi-experimental method with a pretest-posttest control group design was utilized, involving 50 third-grade Physics Education students at an LPTK in Bandung. These students were divided into an experimental group of 26, who engaged with the physics topic using the AG learning model supported by Toulmin's Argumentation Pattern, and a control group of 24, who followed a traditional instructional approach. Quantitative data were collected using an argumentation skills test that assessed students' ability to formulate claims, provide data, construct warrants, and offer backing. The analysis revealed a significant improvement in the argumentation skills of the experimental group, with a considerable effect size (d=2.09). This substantial effect indicates that the AG learning model, supported by Toulmin's Argumentation Pattern, significantly enhances students' argumentation skills. In conclusion, the study demonstrates that the Argument-Generating learning model, when integrated with Toulmin's Argumentation Pattern, is highly effective in improving students' argumentation skills in physics, underscoring its potential as a valuable instructional strategy.

Keywords: argument-generating learning model, Toulmin's argumentation pattern, argumentation skill

INTRODUCTION

Understanding the nature of scientific arguments is crucial for individuals and society in addressing science-related issues that affect all aspects of life. This need encourages everyone to develop critical thinking skills, decision-making skills, ethical considerations, and the ability to evaluate claims presented through various media, including mass media, based on valid and reliable evidence. Argumentation is substantiating claims through the involvement of critical thinking analysis, supported by logical reasoning and evidence. This evidence may consist of objective facts or conditions whose truth can be accepted (Allchin & Zemplén, 2020).

The urgency of this research lies in the growing importance of argumentation skills in today's world, where individuals must navigate complex scientific issues that influence personal and societal decisions. Argumentation skills play a crucial role in science education, particularly in the context of 21st-century education. The current educational paradigm emphasizes

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the importance of students' ability to argue effectively as part of the science learning process. Research shows that learning scientific argumentation can significantly improve science education outcomes, as highlighted by Banihashem et al. (2024), Dawson (2024), Fackler (2021), and García-Carmona (2020). These studies underscore the importance of providing students with opportunities to discuss their ideas, develop arguments based on scientific problems, and express logical and structured argumentation patterns. According to Banihashem et al. (2024), students who engage in argumentation tend to develop a deeper understanding and retain scientific knowledge better than those who rely on passive learning methods. Fackler (2021) found that students trained in structured argumentation showed improved problem-solving abilities and increased engagement in science classes.

With these skills, students can better understand scientific concepts and develop critical and analytical thinking skills essential to science. Scientific argumentation also helps students learn how to collaborate and engage in productive discussions, which are important skills in both academic and professional contexts. Additionally, these skills support more active and problem-oriented learning, preparing students for future challenges in science and technology. For instance, Ping et al. (2020) emphasized how argumentation activities foster an environment where students are more actively involved in scientific inquiry, promoting critical thinking and problem-solving. This is important for several key outcomes. Argumentation is essential in scientific practice, enabling scientists to develop and refine knowledge through debate and evidence evaluation, which drives innovation and ensures the robustness of scientific claims. Beyond academia, it is crucial in everyday life, equipping individuals to critically assess information and engage meaningfully in discussions on scientific issues like climate change and healthcare.

In education, argumentation strengthens students' understanding of scientific concepts by enhancing critical thinking and promoting deeper comprehension, preparing them for academic and professional challenges while fostering informed citizenship in society. Songsil et al. (2019) highlighted that students trained in argumentation show a more remarkable ability to integrate and apply scientific concepts in real-world contexts, demonstrating the power of argumentation as a tool for academic and civic development. Fakhriyah et al. (2022) further argue that argumentation empowers students to become informed participants in societal discussions, such as those surrounding public health and environmental sustainability, which is crucial in a rapidly evolving world. Allchin and Zemplén (2020) and Ping et al. (2020) outline five main dimensions that describe the contribution of argumentation in science learning. First, argumentation involves cognitive and metacognitive processes that align with the performance characteristics of experts, which can serve as a model for students in scientific thinking and working. Second, through argumentation, students develop communication competencies, particularly critical thinking, which are essential for engaging in discussions and debates constructively and reasoned. Third, argumentation also contributes to achieving scientific literacy, where students learn to speak and write using appropriate scientific language. For example, Allchin and Zemplén (2020) found that students who participated in argumentation activities were more likely to use precise scientific terminology and effectively communicate complex ideas. Fourth, through argumentation, students are introduced to the cultural practices of science, including the development of epistemic criteria used to evaluate scientific knowledge. Lastly, argumentation fosters the development of more complex reasoning, where students learn to select theories or positions based on rational, evidence-based criteria. Ping et al. (2020) found that students who engaged in argumentation could better make evidence-based decisions when faced with scientific dilemmas.

Thus, argumentation is a learning tool and an essential life skill supporting scientific literacy, critical thinking, and citizen engagement in scientific issues. In this context, science education must facilitate and actively encourage argumentation in learning. The evidence suggests that fostering argumentation skills in science classrooms is beneficial for academic achievement and critical in preparing students to be informed, rational thinkers in a complex world.

Cankaya and Aydogan (2022) explore the relationship between preservice science teachers' argumentation skills and their levels of cognitive flexibility. Over four weeks, first-year science teaching students participated in argumentation-based science laboratory activities. The quality of their written arguments was evaluated using the Argumentation Assessment Rubric, while their cognitive flexibility was measured using the Cognitive Flexibility Inventory. The researchers examined the connection between cognitive flexibility and argumentation skills through correlation and regression analyses, revealing a significant positive relationship. This highlights the importance of fostering cognitive flexibility to improve argumentation abilities in preservice teachers, enhancing their adaptability and problem-solving capabilities in teaching.

The significance of argumentation skills is further supported by Amielia et al. (2018), which emphasize the critical role of argumentation in science education. It demonstrates that argumentation strengthens students' communication skills and equips them to engage in scientific discussions by forming claims, presenting evidence, and applying reasoning. Instructional strategies such as the Toulmin model and Argument-Driven Inquiry (ADI) have proven effective in cultivating students' argumentation abilities, which are essential for understanding and conveying scientific concepts. Integrating these perspectives develops a more comprehensive understanding of how argumentation fosters critical thinking and deeper learning in science education.

Preservice science teachers, including preservice physics teachers, must be able to develop argumentation skills in science teaching in the classroom (Iwuanyanwu & Ogunniyi, 2020; Lytzerinou & Iordanou, 2020; Masito et al., 2022). Therefore, it is crucial to provide training for preservice science teachers, including preservice physics teachers, to help them develop argumentation skills as a focus in science education. The ability to argue is a critical competency that needs to be built by preservice physics teachers and can be acquired through learning relevant science concepts (Demircioglu et al., 2023; Zhao et al., 2023). Choosing courses with strong concept understanding competencies is also key in shaping optimal argumentation skills.

This study identifies several weaknesses in physics teaching in the Physics Education Program. First, the learning process is often monotonous and lacks challenge, which fails to motivate students sufficiently. Second, the teaching strategies employed are ineffective in encouraging students to think critically and argue, nor do they actively involve students in the learning process. Third, the ideas expressed by students often do not reflect correct scientific explanations and are not well-supported by substantial evidence and reasoning. Lastly, teachers lack the effort to develop collaborative learning, build a learning community through group discussions, and create worksheets emphasizing argumentation skills (Muslim & Suhandi, 2012).

The results of the argumentation skills test conducted by the researcher as part of the preliminary research show that preservice physics teachers have low argumentation skills, with an average score of 44.1 out of a maximum score of 100. Specifically, argumentation skills in each component are still low, with average scores of 48.2 for the ability to make claims, 55.6 for including and analyzing data, 34.3 for making warrants, and 38.4 for providing backing. Interviews with students who took the test revealed that the low argumentation skills are due to difficulties in developing an argumentation pattern, such as making claims, analyzing data, explaining data to support claims or warrants, and providing backing to strengthen claims.

The low argumentation skills found among preservice physics teachers align with Siswanto et al. (2023) and Xie and So (2012), who indicate that preservice science teachers generally have a limited understanding of scientific argumentation. Demivrcioglu (2022) also found that the warrant, a key element of argumentation patterns, is difficult for students to comprehend, suggesting that students' argumentation skills, including preservice physics teachers, still require attention.

Factors mentioned by Beare and Slaughter (2021) are also evident in the context of physics courses at the Teacher Education Institute in Bandung, such as conventional science teaching, student inactivity in constructing scientific knowledge and arguments, and the lack of a learning environment that supports the exchange of ideas. Therefore, developing student-centered, interactive learning patterns that build learning networks through collaboration and encourage active and critical engagement to enhance argumentation skills is important.

Based on these findings, a significant shift in teaching practices is essential to transition from conventional, teacher-centered methods to more interactive, student-focused approaches. This transition prioritizes active learning, enabling students to participate in critical thinking, problem-solving, and argumentation instead of passively absorbing information. By integrating structured frameworks such as Toulmin's Argumentation Pattern into the educational process, educators can promote a more profound comprehension of concepts, facilitate collaborative discussions, and enhance students' skills in formulating and defending arguments grounded in evidence, all while cultivating a supportive learning environment that inspires preservice physics teachers. Strengthening argumentation skills in physics courses should emphasize critical thinking, collaboration, and developing students' potential to construct strong scientific arguments (Li et al., 2023; Landrieu et al., 2024; Fauziah et al., 2024).

Implementing learning strategies oriented toward argumentation skills can positively impact students' abilities to construct and present scientific arguments effectively. The first step is to establish a clear focus for learning, such as developing argumentation skills in physics. Next, a structured lesson plan needs to be developed, which includes appropriate methods and strategies to achieve these goals, incorporating activities that promote critical thinking and collaboration. Once the plan is established, the learning strategies can be implemented in the classroom using interactive methods like group discussions, presentations, or collaborative projects that encourage student engagement. After implementation, it is crucial to evaluate the effectiveness of these strategies by collecting feedback from students regarding their experiences and identifying areas that need improvement. The learning approach should be adjusted based on the feedback and evaluation results to enhance future learning outcomes. Through these steps, argumentation-oriented learning strategies are expected to be integrated, creating a more supportive learning environment for students.

Previous studies on argumentation in science education have identified several gaps, particularly the lack of a structured approach that integrates argumentation techniques into specific topics in physics. Existing models, such as those by Meral et al. (2021) and Smprinis and Skoumios (2021), have demonstrated the benefits of argumentation-based learning but have focused on broader applications or specific physics topics like Ohm's Law without addressing physics concepts in depth.

This research fills the gap by developing a new learning model based on Toulmin's Argumentation Pattern, specifically designed to enhance students' argumentation skills in physics. The model incorporates four main stages: identifying relevant problems, generating tentative arguments, engaging in argumentation sessions, and writing structured arguments. Each stage aims to foster critical thinking, problem-solving, and the ability to construct and defend scientific arguments. This new model is necessary because existing models lack the structured, interactive approach needed to address the complex nature of physics, making it a vital tool for improving argumentation skills in this specific area of science education.

Despite the acknowledged importance of argumentation in science education, significant gaps remain, particularly in enhancing physics students' argumentation skills. Existing studies have highlighted limited understanding and application of scientific argumentation among preservice teachers (Xie & So, 2012; Siswanto et al., 2023; Anwar et al., 2024). However, there is a lack of research focusing on specific strategies to improve these skills in physics concepts. Preliminary findings from this study reveal that preservice physics teachers have low argumentation skills, averaging 44.1 out of 100, with notable weaknesses in making claims, analyzing data, and providing warrants and backing (Demircioglu et al., 2023; Zhao et al., 2023). Current instructional practices often fail to engage students effectively in critical thinking and argumentation, resulting in monotonous learning experiences (Muslim & Suhandi, 2012).

As the world becomes more intricate and science-oriented, the ability to engage in structured, evidence-based argumentation is increasingly essential. This study addresses this urgent need by developing and testing a learning model to enhance students' argumentation skills, ensuring they are well-prepared to contribute to a scientifically literate society. This study develops and tests a novel argument-generating learning model based on Toulmin's Argumentation Pattern, designed for physics to address these gaps. This model introduces a structured, student-centered approach emphasizing interactive learning, collaborative activities, and systematic argument writing. The research aims to improve argumentation skills and contribute to more effective science education practices by focusing on these areas.

This study aims to test the effectiveness of the argument generation learning model assisted by Toulmin's Argumentation Pattern on students' argumentation skills in the physics topic. The aspects to be investigated include: 1) the improvement of students' argumentation skills as a result of the argument generation learning model assisted by Toulmin's Argumentation Pattern on the physics topic, and 2) the effectiveness of the argument-generating learning model assisted by Toulmin's Argumentation Pattern in enhancing students' argumentation skills on the physics topic, as well as the students' responses to the implementation of this learning model.

METHODS

This study utilizes a quasi-experimental approach with a pretest-posttest control group design (Campbell & Stanley, 2015). It involves 50 students from the physics education program at a Teacher Education Institute (LPTK) in Bandung enrolled in a physics course during their third semester. A total of 26 students were assigned to the experimental group, where they participated in the Toulmin-based argument-generating learning model. Meanwhile, 24 students were placed in the control group, which continued with traditional teaching methods. This random assignment ensures that both groups have an equal opportunity to demonstrate their abilities, minimizing potential bias and allowing for a fair comparison of the two teaching approaches.

Data for this study include both quantitative and qualitative types. Quantitative data are derived from argumentation skills test scores obtained through pretests and posttests. The test consists of 20 essay questions designed to assess students' argumentation skills before (pretest) and after instruction (posttest). It was administered to an experimental class that followed the Argumentation-Oriented School Physics Learning Program learning model and a control class that followed conventional teaching methods. The test covered topics in physics, including linear motion kinematics, circular motion kinematics, dynamics, geometric optics, and dynamic electricity. The test was developed based on argumentation skill indicators proposed by Sampson and Gerbino (2010) and was aligned with Toulmin's Argumentation Pattern. In this study, four argumentation skill indicators were measured: 1) making accurate claims relevant to the problem; 2) presenting and analyzing data to support the claim; 3) explaining the relationship between the data and the claim (warrant); and 4) providing justification to support the claim (backing). For each topic, the number of questions associated with the components of argumentation is specified, including Claims, Data, Warrant, and Backing. Specifically, Kinematics of Straight Motion has one question on Claims, two on Data, three on Warrant, and four on Backing, totaling ten questions. Similarly, the Kinematics of Circular Motion includes questions on each component, with a total of ten. Dynamics, Geometric Optics, and Dynamic Electricity follow the same pattern, each contributing four questions to each component. In total, are 20 questions distributed evenly across the four argumentation components. Qualitative data encompass student feedback on implementing the Toulmin-based argument-generating learning model. Improvement in argumentation skills is analyzed using normalized gain scores (Hake, 1999).

Additionally, the quantitative data analysis involves statistical testing. Reliability test results indicate that the argumentation skills test instrument has high reliability (r = 0.87). The effectiveness of the Toulmin-based argument-generating learning model on argumentation skills is evaluated by calculating the effect size (Cohen, 1988). The interpretation of the effect size for this model is based on Cohen's guidelines (1988), as further developed in this study.

Responses from the students' attitude scale towards the Toulmin-based argument-generating learning model were categorized into four groups: Strongly Agree (SA), Agree (A), Disagree (D), and Strongly Disagree (SD). These responses were then analyzed and presented descriptively in quantitative terms.

This study employed a quasi-experimental approach with a pretest-posttest control group design by Campbell and Stanley (2015), involving 50 third-semester students from the physics education program at a Teacher Education Institute (LPTK) in Bandung. The students were divided into two groups: 26 in the experimental group, taught using the Toulmin-based argument-generating learning model, and 24 in the control group, who followed traditional teaching methods.

The research was conducted in several detailed stages. The first stage was the pretest, aimed at assessing the baseline argumentation skills of students in both groups, utilizing a highly reliable test instrument (r = 0.87). In the intervention stage, the Toulmin-based argument-generating learning model was implemented in the experimental group, while the control group continued with conventional instruction; qualitative data were collected through student feedback on the implementation process. Following this, the posttest stage was conducted to evaluate the improvement in students' argumentation skills after the intervention was analyzed using normalized gain scores (Hake, 1999).

The quantitative data were further analyzed statistically to assess the effectiveness of the Toulmin-based argument-generating learning model, including the effect size calculation (Cohen, 1988) based on established guidelines. Additionally, student feedback on the learning model was categorized into four groups: Strongly Agree (SA), Agree (A), Disagree (D), and Strongly Disagree (SD), enabling a comprehensive descriptive quantitative analysis of perceptions regarding the instructional approach. Each research stage was clearly outlined and analyzed using appropriate methods, ensuring data integrity and relevance.

Table 1 illustrates the relationship between the syntax of the argument-generating learning model and students' argumentation skills. It is a critical analytical tool, demonstrating how the model's structured elements enhance these skills. The analysis employed <g> analysis and inferential techniques to deepen our understanding of how the learning model interacts with students' argumentative capabilities, allowing for nuanced conclusions about the instructional strategies' effectiveness.

Table 1. The Relationship Between the Syntax of Argument-generating Learning Model with Argumentation Skills

Syntax	Learning Description	Argumentation Skills
Stage 1: Problem Identification	Students are placed in groups and given student worksheets. The student worksheet displays problems related to the material studied. Students identify the problem. (The whole task on the worksheet is directed at identifying problems, then creating students' desire to generate scientific argumentation).	
Stage 2: Generating of tentative arguments	Students in groups make tentative arguments according to Toulmin's argumentation pattern in the form of claims, data, warrant, and backing related to the problems studied. Students review the teaching materials provided in the MFI to explore evidence or information relevant to the problem. Students actively participate in group discussion activities. Students visualize tentative arguments from group discussions through posters on the whiteboard.	Claims (make accurate claims according to the problem) Data (include and analyze data to support the claim) Justification (Explains the relationship between the data and the claim Support (grounding the justification to support the claim)
Stage 3: Argumentation session	Students present arguments in the form of claims, data, warrant, and backing of the problem using a round-robin presentation structure. Students study and criticize arguments through claims, data, warrants, and backing from other groups. Students communicate ideas and evaluate information.	Claims (make accurate claims according to the problem) Data (include and analyze data to support the claim) Justification (Explains the relationship between the data and the claim Support (grounding the justification to support the claim)
Stage 4: Argument writing	Students return to the initial group to discuss and revise the group's arguments after studying and criticizing the arguments of other groups. The lecturer guides the class discussion. Group representatives present the results of group discussions on the revised arguments in front of the class. Students actively involve themselves in class discussions. Lecturers provide corrections and reinforcement Students write personal arguments according to the problem.	Claims (make accurate claims according to the problem) Data (include and analyze data to support the claim) Justification (Explains the relationship between the data and the claim Support (grounding the justification to support the claim)

RESULTS AND DISCUSSION

To effectively address the research gap related to the role of teacher intervention in developing argumentation skills, the data analysis results provide strong evidence supporting the effectiveness of the argument-generating learning model, particularly when assisted by Toulmin's Argumentation Pattern. Using Toulmin's Argumentation Pattern is essential in educational contexts to effectively enhance students' argumentation skills. This model provides a structured framework that helps students construct well-founded arguments by focusing on key components: claims, data, warrants, backing, qualifiers, and rebuttals (Nasimudheen, 2021; Kapshuk & Alt, 2022). By incorporating Toulmin's framework, students learn to articulate their positions clearly, support them with credible evidence, and address counterarguments systematically.

The teachers' intervention is crucial at every stage in developing argumentation skills. Initially, during classroom sessions, the teachers introduce the problem or challenge that will be the focus of the discussion. At this point, the teachers ensure that students understand the context of the problem and grasp its relevance.

During the interactive poster session, the teachers provide clear guidance on key elements of argumentation, such as claims, data, warrants, and backing. The teachers assist students in formulating relevant claims and gathering data to support these claims. Additionally, the teachers offer examples, explain the concepts of warrant and backing, and provide constructive feedback on the students' progress.

In the final phase, when students present individual arguments, the teachers ensure that their claims remain relevant and backed by strong arguments. The teachers guide students in using credible data, ensuring it closely aligns with the claims, and offer detailed feedback on the warrants and backing to enhance the quality of their arguments.

The teachers use guiding questions, promote group discussions, and acknowledge strong argumentation elements throughout the process. By actively participating, the teachers foster a learning environment that continuously and effectively supports enhancing students' argumentation skills. Examples of Misconceptions in Argumentation When Responding to the Concept of Geometrical Optics are Presented in Figure 1.

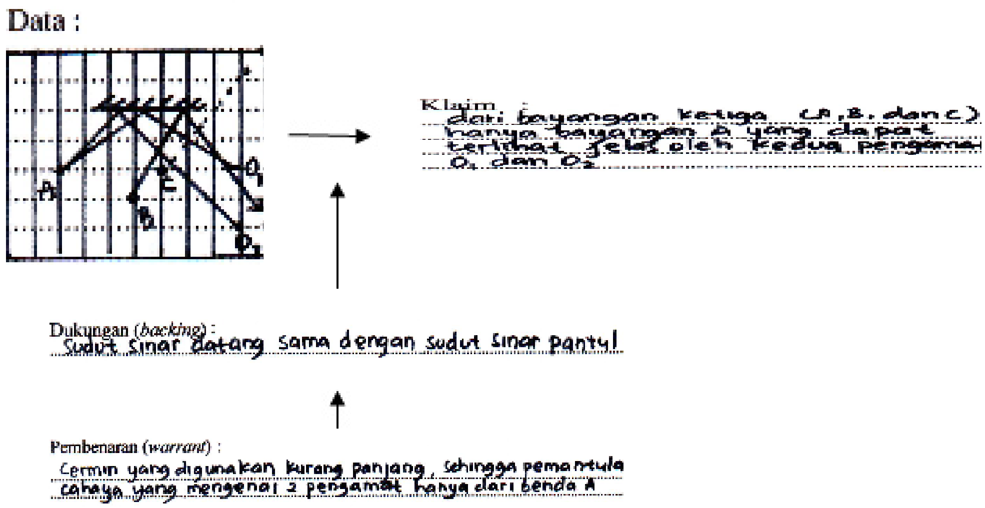


Figure 1. Examples of Misconceptions in Argumentation on the Concept of Geometrical Optics

Improved argumentation skills

The summary of the average normalized gain score (<g>) for students' argumentation skills based on the implementation of the argument-generating learning model assisted by Toulmin's Argumentation Pattern is shown in Table 2.

Table 2. Summary of Normalized Gain Scores (<g>) of Arguing Skills

Class	N	Average		<g>	Criteria
		Pre	Post		
Experiment	26	31.7	75.9	0.65	Middle
Control	24	31.4	59.2	0.41	Middle

Table 2 presents the average normalized gain (<g>) scores for argumentation skills. The experimental class, which employed the Toulmin-based argument-generating learning model, achieved a normalized gain score (<g>) of 0.65, categorized as moderate-to-high, while the control class, which followed conventional methods, scored (<g>) 0.41, categorized as moderate. This indicates a significant improvement in the experimental group, with a notable difference of 0.24 in the average gain scores between the two groups.

Table 3 presents the results of the normality test, homogeneity test, and comparison of average normalized gain scores (<g>) for argumentation skills between the experimental class, which used the Toulmin-based argument-generating learning model, and the control class, which employed conventional teaching methods. These results reflect both classes' normality, homogeneity, and comparison of average normalized gain scores (<g>).

Table 3. Prerequisite Test

Class		**Experiment**	**Control**
N		26	24
<g>		0.65	0.41
Distribution <g>	***p***	0.200	0.200
	criteria	Normalized	Normalized
Variance	***p***	0.831	
	criteria	Homogenous	
t-test	***p***	0.000	
	criteria	Significant	

Table 3 reveals that the average normalized gain score (<g>) for argumentation skills in the experimental and control classes follows a normal distribution and exhibits homogeneous variances. The t-test results demonstrate a significant difference in the average improvement of argumentation skills between the two classes. The Toulmin-based argument-generating learning model significantly improves students' argumentation skills.

Figure 2 compares average normalized gain scores (<g>) for each argumentation skill component between the experimental and control classes. In the experimental class, the highest average normalized gain score (<g>) is for the ability to include and analyze data, at 0.72, considered high. The lowest is for explaining the relationship between data and claims (warrant), at 0.60, classified as moderate. In the control class, the highest average normalized gain score (<g>) is also for including and analyzing data, at 0.54, classified as moderate, while the lowest is for explaining the relationship between data and claims (warrant), at 0.26, classified as low. Overall, the experimental class shows a more remarkable improvement in all components of argumentation skills compared to the control class.

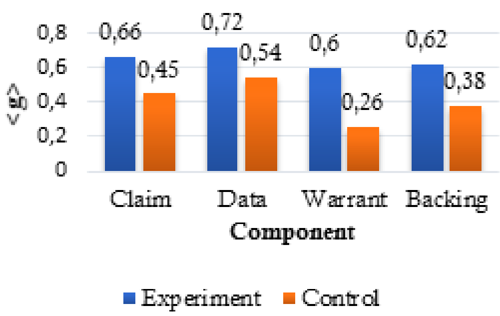


Figure 2. Comparison of Normalized Mean Gain Scores (<g>) for Each Component of Argumentation Skills

The results of the normality, homogeneity, and comparison of two means tests for normalized gain scores (<g>) for each component of argumentation skills between the experimental group, which used Toulmin's Argumentation Pattern-based argument-generating learning model, and the control group, which used conventional teaching methods, are shown in Table 4.

Significant differences were found in the average improvement scores for accurately formulating claims, incorporating and analyzing data to support claims, explaining the relationship between data and claims through warrants, and providing backing for claims between the two groups. These findings suggest that the Toulmin-based argument-generating learning model significantly improves all aspects of argumentation skills.

Table 4. Summary of Statistics test

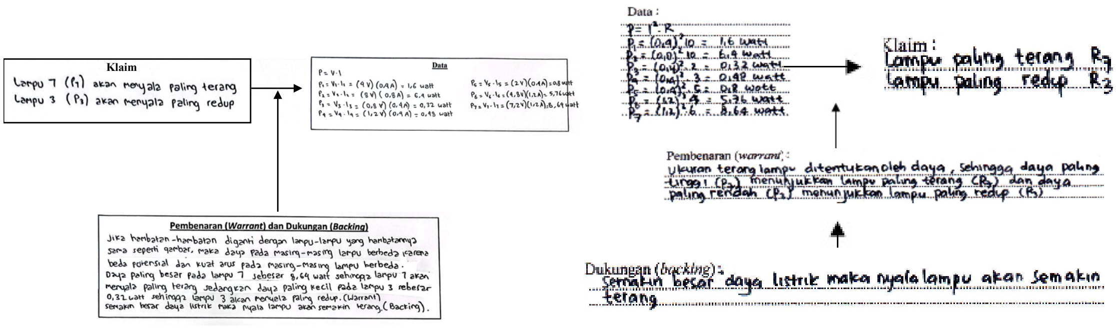
Aspects	Experiments				Control				Variance		T-test	
	<g>	Criterion	Distribution		<g>	Criterion	Distribution					
			p	criterion			p	criterion	p	criterion	p	criterion
Claim	0.7	Moderate	0.2	Norm	0.45	Moderate	0.03	Abnorm.	0.65	Homog.	0.0	Sig.
Data	0.7	High	0.2	Norm	0.54	Moderate	0.2	Norm	0.07	Homog.	0.0	Sig.
Warrant	0.6	Moderate	0.6	Norm	0.26	Low	0.2	Norm	0.835	Homog.	0.0	Sig.
Backing	0.6	Moderate	0.09	Norm	0.38	Moderate	0.13	Norm	0.135	Homog.	0.0	Sig.

The effectiveness of the argument-generating learning model assisted by Toulmin's Argumentation Pattern was analyzed for argumentation skills using effect size calculations. The statistical data description for argumentation skills, used for calculating the effect size (d), is presented in Table 5.

Table 5. Effect Size

	Pretest	Posttest
N	26	26
Average	37.1	75.9
St Dev	7.3	7.7
$(\text{St Dev})^2$	53.3	59.0
Effect Size (d)	2.09	
Criterion	Very High	

The impact of the Toulmin-based model is further demonstrated through the effect size analysis presented in Table 5. The posttest results show a very high effect size (d = 2.09), indicating that the model has a substantial impact on improving argumentation skills. This aligns with previous research, which suggests that argument-based learning strategies, particularly those incorporating Toulmin's Argumentation Pattern, significantly improve students' ability to construct coherent and persuasive scientific arguments. The sample test results from the experiment and control class can be seen in Figure 3.



(a) (b)

Figure 3. (a) Example of Proper Argumentation Skills on Dynamic Electricity Material in the Experimental Class, (b) Example of Inadequate Argumentation Skills on Dynamic Electricity Material in the Control Class

The research findings demonstrate that the argument-generating learning model, which utilizes Toulmin's Argumentation Pattern, is significantly more effective in enhancing students' argumentation skills than traditional teaching methods. The research findings demonstrate that the argument-generating learning model, which utilizes Toulmin's Argumentation Pattern, is significantly more effective in enhancing students' argumentation skills than traditional teaching methods. This effectiveness can be directly linked to the syntax or steps of the model, where each phase strategically contributes to achieving specific outcomes.

For instance, improving students' ability to generate structured and evidence-based arguments was practiced during the argument-generating phase of the model. During this phase, students were guided to form claims and provide supporting evidence (data) corresponding to Toulmin's model's claim and data components. The structured nature of this phase helps students clarify their reasoning, making it easier for them to justify the relationship between claims and data through warrants. According to Toulmin's theory (2003), this step is fundamental in strengthening argumentation skills, as it encourages students to think critically about how data supports their claims, a key to developing sound arguments.

The problem identification phase also played a crucial role by helping students understand the problem before generating their arguments. Fischer et al. (2014) underscore that a clear understanding of the problem is essential for constructing strong arguments. By guiding students through problem analysis and claim formulation, this phase ensured that their arguments were grounded in relevant contexts, contributing to the improvement observed in their posttest.

Moreover, the systematic argument-writing phase enhanced students' ability to connect their arguments logically and cohesively. Wolfe et al. (2018) emphasize that developing warrants, which explain how the evidence supports the claim, is often the most challenging part for students. The TAP-based model provided structured guidance during this phase, allowing students to practice creating clear warrants and backing, improving their overall argumentation quality. This step-by-step guidance ensured that students identified appropriate data and linked it effectively to their claims through justified reasoning.

Regarding student responses, the model garnered positive feedback, with most students agreeing that the argument-generating learning approach helped them understand and practice argumentation more effectively. This aligns with Groth and Choi (2023), who suggest that structured argumentation models like Toulmin's Argumentation Pattern foster greater student engagement and deeper learning. Students' feelings of empowerment and clarity in their learning process indicate that they appreciated the model's systematic approach to argumentation, reducing the complexity often associated with formulating logical arguments.

These positive responses also align with Feijoo-Garcia et al. (2024), who found that students tend to respond more favorably to argument-based learning models because they provide a clear framework for constructing logical arguments. The structure reduces ambiguity and helps students feel more confident in their abilities to build evidence-based claims, which likely contributed to the model's success.

This model outperforms conventional approaches by providing a structured framework that helps students develop their ability to formulate claims, support arguments with evidence, and reason logically (Gultepe and Kilic, 2015; Pimvichai et al., 2019; Nasimudheen, 2021; Kapshuk and Alt, 2022). The effectiveness of this model aligns with existing literature, which indicates that argument-based learning strategies can substantially improve argumentation skills. Acar et al. (2015), Songsil et al. (2019), and Uzuntiryaki-Kondakci et al. (2021) have consistently shown that incorporating argumentation into science education not only enhances preservice teachers' ability to construct coherent and persuasive scientific arguments but also positively influences their conceptual understanding and written scientific argument structures.

Furthermore, Lin et al. (2020) and Ural and Gençoğlan (2019) support the effectiveness of argument-based science education in improving students' academic performance and scientific process skills. Their findings indicate that argumentation-focused learning environments foster critical thinking, analytical reasoning, and a deeper engagement with scientific content. The Toulmin-based model effectively supports these outcomes by providing a systematic approach to argument construction. The model's structured methodology—comprising stages like problem identification, argument-generating, and systematic argument writing—facilitates a comprehensive learning experience that enhances students' overall argumentation competencies. These results highlight the need for educational strategies emphasizing argumentation, suggesting that traditional teaching methods may fail to develop the critical thinking and reasoning skills necessary for scientific literacy. Educators can better equip students with the skills needed to engage in rigorous scientific inquiry and discourse by adopting argumentation-based learning models like Toulmin's.

Fischer et al. (2014), Hendratmoko et al. (2024), Martini et al. (2021), and Lestari et al. (2024) state that developing argumentation in science education has the potential to encourage active student participation, help students understand and construct scientific arguments, and guide them in thinking about the data needed to support claims, thus increasing argumentation activities in the classroom. A productive way to help students achieve educational outcomes in science is to provide them with opportunities to learn about scientific arguments within science education (Jerrim et al., 2022; Jimenez et al., 2024). Preservice teachers must learn to build arguments because their argumentation skills will be highly valuable when they later perform their teaching duties. The observed enhancement in students' argumentation skills, resulting from implementing the Toulmin-based argument-generating learning model, allows students to engage collaboratively in scientific argumentation. This approach allows students to effectively construct scientific arguments by addressing complex issues related to the physics being studied. Through this method, students learn to grasp problems, solve them using available information by formulating claims, incorporate and analyze data to support these claims, clarify the relationship between data and claims through warrants, and reinforce these warrants with backing to substantiate the claims.

The achievement in improving students' argumentation skills remains in the moderate category and has not reached the high category. This is suspected to be due to several students still experiencing difficulties constructing argumentation patterns for some physics problems. Some students are still inaccurate in making precise claims, analyzing data, explaining the relationship between data and claims in the form of warrants, and supporting the warrants with backing. For example, the answers can be seen in Figure 4.

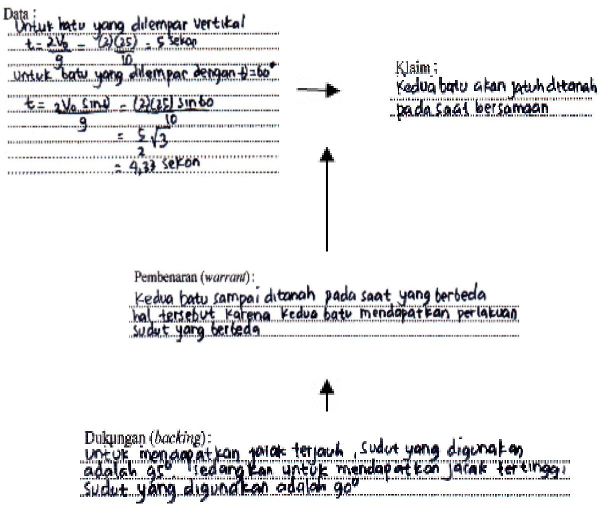


Figure 4. Example Answers on Argumentation Skills in Linear Motion Kinematics

In the case of constant linear motion involving two objects (one object is thrown vertically upward, while the other is thrown at an angle α with the same initial velocity and reaching a certain height), some students incorrectly claim that the time required for both objects to hit the ground will be the same. However, they correctly included and analyzed the data to support this claim. Students still make errors in justifying the relationship between the data and the claim, such as not explaining why the key factor $t = f(\alpha)$ is sinusoidal, where a more minor α results in a shorter Δt. Only partial justification (warrant) supports the claim.

The warrant for supporting the claim should be that the time $t = f(\alpha)$ is sinusoidal: as the angle α decreases, Δt becomes shorter. The time required for the first object, which is thrown vertically upward, will be longer than the time needed for the second object, which is thrown at an angle α. Thus, both objects will hit the ground simultaneously due to the different velocity impacts along the Y-axis(v_y); v_y in vertical motion is more significant than v_y in projectile motion. The students' backing only partially supports the accurate claim. For example, they only explain that the angle used for achieving the farthest distance is 45°, while for achieving the highest point, the angle is

90°. Proper backing should establish that for vertical motion, as the object rises, its velocity decreases until it reaches zero at the highest point. The object momentarily stops and then falls back down. For the first object thrown vertically upward, the time to reach the ground is given by the equation $t = 2v_o/g$. For the second object thrown with an initial velocity v_o and elevation angle α, its velocity can be projected onto the horizontal (x-axis) and vertical (y-axis) components. The farthest point is reached when y = 0. If this assumption is not followed, the farthest point will vary with height (y). The time to reach the farthest point is given by $t = 2v_o \sin \alpha/g$.

Based on the argumentation patterns constructed by students, it is evident that some students' statements are accurate while others are not (Widodo et al., 2016; Ramadhani et al., 2023). Osborne et al. (2004) suggest that inaccurate claims may result from lacking supporting data, noting that "... claims are justified by linking them to the underlying data." Machost and Stains (2023) and Ranjbaran et al. (2023) state that students' claims are not intended to alter perspectives but to encourage critical reflection. If students' statements are inaccurate because data do not support them, they do not need to revise the initial statement about the problem; instead, they should reflect that not every statement about a problem is always correct; instead, it requires data to verify its accuracy. Truth is the result of reasoning within argumentation.

Some students' ability to analyze data fully supports the claims, while others only partially support them. Overall, students are capable of including and analyzing data correctly. Osborne et al. (2004), Seppanen (2022), and Wiese et al. (2023) argue that data is crucial in argumentation as it serves as evidence to support or refute claims. Argumentation requires careful data analysis to establish validity (Toulmin, 2003). Similarly, students' abilities to create warrants vary: some fully support the claims, while others only partially do. Osborne et al. (2004), Haro et al. (2020), and Lin and Wei (2024) state that "a warrant is essentially the meaning where data is linked to a claim, justifying belief." The foundation of argumentation is critical and logical thinking. Thus, argumentation must start from existing data as evidence. Argumentation requires clarity and confidence through accurate data. With accurate data, one can construct a logical narrative through warrants that lead to a justifiable conclusion or an acceptable claim (Toulmin, 2003). Interviews with several students revealed that the ability to create warrants is the most challenging among the four components of argumentation. In writing warrants, students need only to explain the relationship between data and claims; Wolfe et al. (2018) state, "a warrant is the reason connecting data to the claim." Godfrey and Erduran (2023) and Hasnunidah et al. (2020) assert that a strong argument has multiple relevant and specific justifications (warrants) to support claims with accurate data.

Some students' ability to provide backing for justification varies: some fully support the claims, while others only partially support them. Backing can include theories that underpin the problem. Therefore, it is crucial for students to thoroughly understand the instructional material to create backing that serves as a basis for justification to support accurate claims. Some students still struggle to provide backing supported by a strong understanding of concepts directly related to the problem, possibly due to their lack of familiarity with using theory to strengthen their arguments. In the learning process through Toulmin's Argumentation Pattern-based argument-generating model, students can develop backing by studying the instructional materials provided in the student activity sheets (SAS) for each topic and listening to corrections and reinforcement from the teachers to enhance their conceptual understanding.

These findings align with previous research emphasizing the benefits of argument-based learning strategies in improving students' abilities to construct coherent and persuasive scientific arguments (Hasnunidah et al., 2015; Zhang et al., 2023). Studies have shown that such models enhance students' ability to evaluate information critically, apply theoretical concepts, and construct logical justifications (Wolfe et al., 2018; Godfrey & Erduran, 2023). The Toulmin-based model provides a framework that promotes more profound engagement with content, enabling students to use theories as a foundation for building strong and valid arguments.

The statistical tests supporting this model further underline its effectiveness. Significant differences in normalized gain scores across various components of argumentation skills demonstrate that students who engage with the Toulmin-based model outperform those who rely on conventional learning methods. This evidence suggests that the model improves students' ability to generate backing and fosters overall argumentation competence. Students develop critical reasoning skills essential for academic success and future problem-solving scenarios by integrating theoretical understanding with practical applications.

The analysis of student responses using the attitude scale reveals the following: for positive statements, 23.8% of students strongly agreed, 69.7% agreed, and 4.5% disagreed. For negative statements, 8.1% of students agreed, 64.4% disagreed, and 27.7% strongly disagreed. Thus, 95.5% of students agreed with positive statements, and 91.9% disagreed with negative statements. This indicates that nearly all students concur that Toulmin's Argumentation Pattern-based argument-generating model effectively trains argumentation skills.

Students' approval of the Toulmin-based argument-generating model aligns with the observed improvement in argumentation skills among students who experienced this model compared to conventional learning settings. The application of the Toulmin-based argument-generating model encourages students to actively engage in scientific argumentation, which supports the development of argumentation skills, the construction of knowledge based on data, collaboration, and the development of concepts and interconceptual relationships based on direct experience (Telenius et al., 2020; Mirzababaei & Pammer-Schindler, 2021; Groth & Choi, 2023; Feijoo-Garcia et al., 2024).

Additionally, the overwhelmingly positive feedback from students underscores the model's capacity to create an engaging and motivating learning environment, fostering confidence and a positive attitude toward scientific inquiry. Students reported that the framework improved their ability to argue scientifically and increased their interest and active participation in learning activities. These findings are consistent with prior research demonstrating how argument-based learning models can transform traditional learning settings into dynamic environments that prioritize student-centered inquiry and collaboration (Mirzababaei & Pammer-Schindler, 2021; Groth & Choi, 2023).

Moreover, the collaborative activities integrated into the model mirror real-world scientific practices, emphasizing team-based problem-solving, critical reasoning, and the construction of knowledge based on evidence. This alignment with authentic scientific processes prepares students for challenges beyond the classroom, equipping them with essential skills for higher education and professional contexts (Tang et al., 2020; Bolger et al., 2021). The model's success is further evidenced by significant improvements in students' argumentation skills, as indicated by statistical tests and normalized gain scores.

Overall, the Toulmin-based argument-generating model enhances students' ability to construct arguments and supports broader educational objectives. By promoting critical analysis, collaboration, and conceptual understanding, the model is a transformative approach to science education, fostering skills vital for academic success and lifelong learning.

The intervention, specifically the argument-generating learning model assisted by Toulmin's Argumentation Pattern, demonstrated a significant positive impact on students' argumentation skills compared to traditional teaching methods. Multiple statistical analyses, including normalized gain scores, t-tests, and effect size calculations, consistently show that the experimental group significantly outperformed the control group in all measured aspects of argumentation.

These findings reveal that the improvement in argumentation skills in the experimental class, which utilized Toulmin's Argumentation Pattern, was markedly superior to that of the control class. For example, the normalized gain score for the experimental group was higher across all components of argumentation, particularly in analyzing data and making claims, where the experimental group displayed a "high" improvement compared to the "moderate" and "low" improvements seen in the control group. The significant differences in the average improvement scores between the experimental and control groups and the high effect size observed provide robust evidence that the Toulmin-based model effectively bridges the gap in argumentation skills development.

Furthermore, the research findings align with existing literature, reinforcing the model's utility in fostering critical thinking, analytical reasoning, and scientific inquiry among students (Heng et al., 2014; Nussbaum, 2020; Liu & Xiong, 2024). This comprehensive analysis confirms the efficacy of the argument-generating learning model and highlights its potential to address the critical gaps in traditional teaching methods, thereby contributing to the ongoing discourse on improving educational strategies for developing argumentation skills.

This study introduces a novel approach by integrating Toulmin's Argumentation Pattern with an argument-generating learning model tailored explicitly for the development of argumentation skills in the context of physics education. Unlike previous studies that have primarily focused on general applications of argumentation in science education, this research provides a detailed, systematic framework that guides students through each stage of argument construction, from problem identification to the formulation of well-supported claims.

The innovation lies in combining Toulmin's model with an interactive poster session and individual argument phases, which prior research has not explored extensively. This approach enhances students' ability to construct coherent and persuasive arguments and provides a structured mechanism for teachers to intervene effectively at critical points in the learning process (Iordanou & Rapanta, 2021; Wambsganss et al., 2024).

Moreover, the study offers empirical evidence demonstrating the significant impact of this integrated model on students' argumentation skills, as shown by the superior performance of the experimental group compared to the control group. Normalized gain scores, t-tests, and effect size calculations provide robust statistical support for the model's effectiveness, contributing new insights to science education.

In addition to confirming the utility of Toulmin's Argumentation Pattern in enhancing critical thinking and analytical reasoning, this research fills a gap in the existing literature by offering a practical, replicable model that can be adapted for use in other educational contexts. The findings suggest that this approach improves students' argumentation skills and has broader implications for the development of scientific literacy and inquiry-based learning (Witherspoon et al., 2022).

CONCLUSION

Based on the findings of this study, it can be concluded that the Toulmin-based argument-generating model effectively enhances students' argumentation skills, particularly in the topic of physics. Students who engaged in this model improved their argumentation skills more than those who received conventional instruction. This improvement includes making claims, analyzing data, explaining the relationship between data and claims, and providing justification that supports claims. The model positively impacts conceptual understanding and strengthens students' critical and argumentative thinking skills. Furthermore, most students agree that this model effectively trains their argumentation skills, indicating a significant contribution to science education, especially in developing critical thinking abilities among future physics teachers.

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