AMPLITUDO 4(2) (2025)

AMPLITUDO: Journal of Science & Technology Innovation

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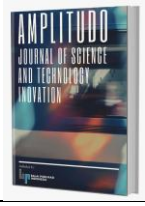

Project Based Learning Model on Students' Critical Thinking Skills on the Material of Elasticity and Hooke's Law

Helmayani Lestari[1*], Aris Doyan[1], Jannatin 'Ardhuha[1], Ahmad Harjono[1]

[1] Physics Education, Faculty of Teacher Training and Education, University of Mataram, Lombok, West Nusa Tenggara, Indonesia

Received: June 25, 2025
Revised: August 12, 2025
Accepted: August 27, 2025
Published: August 31, 2025

Related Authors:
Helmayani Lestari
lestarihelmayani@gmail.com

DOI: 10.56566/amplitudo.v4i2.427

Abstract: This study aims to determine the effect of the *project-based learning model* on students' critical thinking skills on elasticity and Hooke's law. The population in this study was all class XI MIPA SMAN 1 Terara. Sampling was carried out using a *purposive sampling technique*, so that class XI MIPA 1 as many as 30 people as the experimental class and class XI MIPA 3 as many as 30 people as the control class. The type of research used was *a quasi-experimental* with a *nonequivalent control group research design*. The instrument used was a descriptive test of 5 questions. Post-test data were analyzed using a normality test using the chi-square formula and homogeneity test using a variance test, then hypothesis testing using a polled variance t-test, because the number of students in the experimental and control classes was the same and the data was distributed homogeneously. This test was conducted to determine whether or not there was an effect of the *project-based learning model* on students' critical thinking skills. Data analysis shows that the values t_{count} are 5,90 and t_{table} 2,00, so that $t_{count} > t_{table}$ it means there is a positive influence of the *project-based learning model* on students' critical thinking skills in the material on elasticity and Hooke's law.

Keywords: Critical thinking skills; Project-based learning; Students

Introduction

Education is the container provided to participant educate to acquire knowledge, experience and opportunities so that the information he receives can change life gets better (Rosmiati) *et al*, 2022). Educational objectives in the 21st century are realizing ideals of national nation, namely giving birth to generation competent, motivated and highly capable young people compete with the global world. The current learning process is guided by four learning characters, namely communication, collaboration, critical thinking and problem-solving problems, and creativity and innovation (Fadriati *et al*, 2023).

The achievement of learning outcomes in Indonesia is still classified as low especially in science learning. One of them Lessons that are included in science learning are eye lesson physics (Arlina *et al* , 2022). Physics is lessons that provide knowledge about natural the inseparable universe from mastery concepts, formulas, and their application in everyday life (Septyaningrum and Nurita, 2023). A participant student who studies physics is required to master principles and concepts physics because based on concepts and principles the participant educate will capable develop thinking critical participant useful education to complete daily problems (Taufik and Aris, 2022).

Critical thinking is one of the 21st century learning objectives that must be mastered participant educate . By thinking critically, participants students can show objective specific, interpret and solve problems in the learning process (Suci *et al,* 2022). According to Rahayu and Festiyed (2023), when participant educate centralize his mind to find settlement certain from something problem then he currently develop critical thinking skills . Novalianti *et al* (2021), participants' thinking abilities educate divided into basic thinking and advanced thinking. Advanced level thinking high (*higher order thinking*) makes participant educate analyze

How to Cite:
Lestari, H., Doyan, A., 'Ardhuha, J., & Harjono, A. (2025). Project Based Learning Model on Students' Critical Thinking Skills on the Material of Elasticity and Hooke's Law. *AMPLITUDO: Journal of Science and Technology Innovation*, *4*(2), 84–91. https://doi.org/10.56566/amplitudo.v4i2.427

information whereas high-level thinking skills basic (*lower order thinking)* using skills participant educate. As per opinion Syahrul (2021), that individuals who have Good critical thinking skills tend to be able to learn more effectively, so that participant educate capable process information better and improve the learning outcomes that have been achieved so far. implemented by participants educate .

Based on initial observations conducted at SMAN 1 Terara, it was found that those teachers still use conventional learning models in the teaching and learning process. Learning is still nature *teacher center* (focused on the teacher) where the teacher delivers material and gives practice questions to participant educate without existence direct application regarding the material being taught. Based on the results of teacher interviews, learning activities experienced constraint Because participant students are less proficient in mathematics or calculations, so that participant educate experience difficulties in learning physics. This makes participant students become unenthusiastic and feel that lesson physics is something boring. In addition, critical thinking learning has not been implemented in learning activities, so that participant students have not received experience about application of critical thinking in learning.

Response data results from distribution questionnaire against 30 participants studied at SMAN 1 Terara, namely as many as 13 participants educate like learning physics and feel that The atmosphere in learning physics is quite pleasant, but there were also 17 participants students who feel that the physics learning atmosphere is not very pleasant because they are difficult to understand and memorize the formula in the eye lesson physics. Apart from that, there are also quite a few who state that that there is difficulty in understanding problems in physics that make participant students become less able to solve physics problems.

Based on the above problems changes in physics learning in schools need to be addressed to make it easier and attract the interest of students in learning physics. Teachers must apply a variety of learning models as well as involving participant students in classroom learning. So, the alternative is using a participant-centered learning model educate, one of them is the expected project-based *learning* model able to improve critical thinking skills participant educated. The results of the research that has been conducted by Devi *et al* (2019), show that existence increase in independence participant students when implementing this *project-based learning* model.

Project-based learning leads towards participant-centered learning educate using real and contextual projects. So that it can overcome passive learning problems, PjBL put participant educate as subject active in designing, working on and reflecting on their own projects. This can train critical thinking skills participant educate with problem-based learning problem real that connects draft physics on elasticity and Hooke's law with practice directly. This gives experience concrete that deepens understanding draft elasticity and Hooke's law through experiment real and improving ability participant learn to solve problems problem physics systematically. As research has shown conducted by Gaffar (2023), this *project-based learning model* can change participant learning independence educate to find solution problem so that capable develop critical thinking skills. Due to the reasons said, researchers interested in conducting research entitled" The Influence of *the Project Based Learning* Model "On Students' Critical Thinking Skills on Elasticity and Hooke's Law Material".

Method

The research was a quasi-experimental study with a *nonequivalent control group design*. Two classes were selected as samples: one class as the control class and the other as the experimental class. Prior to the learning process, both classes were given *a pre-test* to assess students' initial critical thinking skills on elasticity and Hooke's law.

The control class was given treatment in the form of a conventional learning model (not given the *project-based learning model treatment)*, while the experimental class was given treatment in the form of a *project-based learning model*. At the end of the research activity, students in both classes were given a final test to determine their critical thinking skills after being given the treatment. The design of this study can be seen in Table 1.

Table 1. Research design with *nonequivalent control group*

Class	*Pre-test*	Treatment	*Post-test*
Experiment	0_1	X_1	0_2
Control	0_3	-	0_4

(Sugiyono, 2022)

Information :

0_1 = Giving a pretest to the experimental class.
0_2 = Posttest administration in the experimental class.
0_3 = Giving a pretest to the control class.
0_4 = Posttest administration to the control class.
X_1 = *Project based leaning* model treatment .

This research was conducted at SMAN 1 Terara, NTB. The sample was selected using *purposive sampling* , a sampling technique that considers certain factors such

as the same initial abilities of students and the fact that grade XI students at SMAN 1 Terara have not yet studied elasticity material. This study consisted of two classes, namely XI MIPA 1 with 30 students as the experimental class and XI MIPA 2 with 30 students as the control class. The critical thinking ability test instrument consisted of 5 essay-style questions. Previously, the test instrument used in the study had to meet several requirements, namely validity using the *product moment correlation equation* , reliability using the Alpha equation, the level of difficulty and the discrimination power of the questions (Saputri et al, 2023). After the test instrument met the requirements, the next stage of this study was to administer *a pre-test* and *post-test* to students in the experimental and control classes to determine the students' initial abilities and their final abilities after being given the treatment. The *pre-test* and *post-test questions* tested were 5 essay-style questions. The critical thinking indicators used according to Facione in this test consist of four indicators: interpretation, analysis, evaluation, and inference (Nuraini, 2022). As for the category of critical thinking abilities, they are divided into 3 categories, as follows on Table 2.

Table 2. Critical thinking category guidelines

Value Range	Category
0 - 60	Low
61 - 75	Currently
76 - 100	Tall

(Nurmayanti, 2018).

Table 3. Categories of n-gain values

Value Range	Category
N-Gain < 0.30	Low
0.30 ≤ N-gain ≤ 0.70	Currently
N-Gain > 0.70	Tall

(Kurniawan & Rusly, 2018).

After that, the data was tested for normality and homogeneity. The normality test used the chi-square formula (Sugiyono, 2022). The data is said to be normal if $X^2_{count} < X^2_{table}$. The homogeneity test used the variance test (Muhid, 2021). The data is said to be homogeneous if $F_{count} \leq F_{table}$. Furthermore, the hypothesis test used in this study was the *polled variance t- test* with a significance level of 5% (Asari, 2023). The test was conducted to determine whether or not there was an effect of the *project-based learning model* on students' critical thinking skills. The data hypothesis was accepted if $t_{count} > t_{table}$. Furthermore, as an additional test, the N-Gain test was used to determine the increase in critical thinking skills per indicator in the experimental and control class groups. As for the N-gain value range category, it is shown in Table 3.

Results and Discussion

This study aims to determine the effect of the *project-based learning model* on students' critical thinking skills and learning outcomes in the elasticity and Hooke's law material. According to Facione, there are four indicators of critical thinking skills, namely interpretation, analysis, evaluation, and inference (Nuraini, 2022). Class XI MIPA 1, as the experimental class, was given the *project-based learning model* , while Class XI MIPA 3, as the control class, was given the conventional learning model.

The data on students' critical thinking skills on elasticity and Hooke's law consisted of *a pretest* and *a posttest* . The *pretest* was given to the experimental and control classes to determine students' initial abilities on elasticity and Hooke's law. Meanwhile, the *posttest* was given to determine students' final abilities after the *project-based learning model was applied to the experimental class and the conventional learning model to the control class. The pretest* and *posttest* data on students' critical thinking skills in the experimental and control classes are presented in Figure 1.

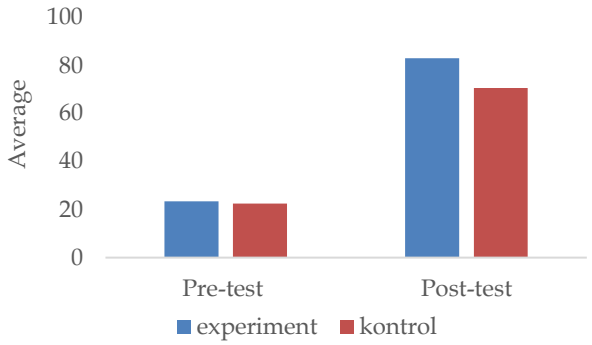

Figure 1. Average results of *the pretest* and *posttest* of students' critical thinking skills.

Based on Figure 1 above, it can be seen that the *pre-test scores* in the experimental and control classes are almost the same. It was obtained that the average *pre-test score* of the experimental class in physics learning on elasticity and Hooke's law was 23,50, higher than the control class, which was 22,56. Meanwhile, the *post-test score* of the experimental class was higher than the *post-test score* of the control class. The average *post-test score* of the experimental class, which was 83,10, was higher than the average score of the control class, which was 70,70. This shows that students' scores were superior after being given treatment in the experimental class in the form of a *project-based learning model.*

Next, data is presented on the value obtained for the critical thinking ability category of students in the experimental class and control class of SMAN 1 Terara on the elasticity and Hooke's law material.

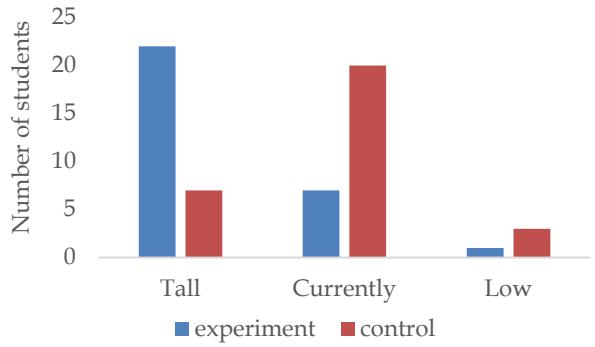

Figure 2. Distribution of students' critical thinking skills based on value categories.

Based on Figure 2, it can be seen that the critical thinking ability category of students in the experimental class was higher than that of the control class. In the experimental class, 22 students were classified as having high critical thinking, 7 students were classified as having medium critical thinking, and 1 student was classified as having low critical thinking. Meanwhile, in the control class, 7 students were classified as having high critical thinking, 20 students were classified as having medium critical thinking, and 3 students were classified as having low critical thinking. This indicates that the results of critical thinking that were classified as having high critical thinking in the class using the *project-based learning model* were relatively more numerous.

(a) (b) (c)

Figure 3. Simple project on elasticity and Hooke's law.

Experimental class students were given the task of creating a project or product related to the material on elasticity and Hooke's law. There were two groups making simple bow arrows, two groups making simple fishing arrows, and two groups making catapults. During the project creation process, students actively sought out the working principles of the tools and matters related to the material of elasticity and Hooke's law. The project created by these students applied the concept of Hooke's law, namely the relationship between the force applied to an elastic object and the resulting change in length (deformation). Hooke's law only applies as long as the object remains within the elastic limit. The elastic limit is the limit at which an object can return to its original shape after the applied force is removed. In this project, when the arrow is placed on the bowstring and then pulled, it will provide a force to bend the bow arm on the bowstring. The bow arm will provide a restoring force that is directly proportional to the length of the throw or the distance the bow is thrown. This is in accordance with the concept of Hooke's law, as long as the rubber does not exceed the elastic limit.

Based on this, after the learning process using the *project-based learning model* in the experimental class and the conventional learning model in the control class, it was found that the results of the data analysis were normally distributed and homogeneous. Data testing used the *chi-square formula* to determine the normality of the data. For *the pre-test, a chi-square* value of 9,18 was produced for the experimental class and 10,44 for the control class with a chi-table value of 11,07, which indicates that the data was declared normal because *chi-square* < chi-table. For *the post-test,* a chi-square value of 7,32 was produced in the experimental class and 9,03 for the control class, a chi-table value of 9,03 was produced in the control class with a chi-table value of 11,07, which indicates that the data was declared normal because *chi-square* < chi-table. In addition, data testing also used a variance test to determine the homogeneity of the data and the resulting value $F_{count}$for the *pre-test* was 1,31 with F_{table} 1,86 and the value F_{count} for *the post-test* was 1,23 with F_{table} 1,86, which indicates that the value $F_{count}<F_{table}$ so that the data was declared homogeneous.

After the data was normally distributed and homogeneous, the next step was to test the hypothesis using *a polled variance t-test*. The *polled variance t-test* was conducted to determine the effect of the *project-based learning model* on students' critical thinking skills. The test results can be seen in Table 4.

Table 4. Hypothesis testing

Class	Amount participant educate	Ave-rage	Vari-ance	t_{hitung}	t_{tabel}
Experiment	30	83,10	59,13	5,90	2,00
Control	30	70,70	73,10		

Based on Table 4 it can be seen that the average value of the experimental class is 83,10 with a variance of of 59,13. The average of the control class is 70,70 with variance of 73,10. The t-test results show that $t_{count} > t_{table}$ namely 5,90 > 2,00 which means there is influence significant from this *project based learning* model towards critical thinking skills participant educate.

The use of the *project-based learning* model involves several phases. important thing that drives critical thinking activities such as, in the first syntax of this

model, namely determination question fundamental, in this case the participants educate directed to solve problem real in everyday life related to the material of elasticity and Hooke's law, such as when making arrow bow, fish arrows and slingshot. This is training participant educate to interpret problems appropriately in accordance with the first indicator of critical thinking skills. Participants educate train the ability to identify, understand and formulate problems independently based on situation. For example, when making bow or catapult, participants educate interpret about importance elasticity and the project.

Next on the syntax project design, participants students are asked to compose plans in the making the project. After that, the participants educate make the project directly, such as attracting rope arc arrows and observing style restorer participant educate analyze component physics relevant to the project such as determining long elasticity material. This train's ability participant educates in evaluating.

During the project creation process, participants educate actively find out about working principles of tools and things others related to the material of elasticity and Hooke's law. As in a catapult, when the catapult withdrawn will happen strain on the rubber. The bigger style the pull exerted by the object will the more experience stretching. Next on the simple fish arrow and bow, its size style pull will influence how far the arrow will be shot. When the rope released, arm arc trying to get back into position Originally, this was related to the concept style restorer. Based on the process of creating the project, participants educate will learn to analyze and evaluate His project is related to the material of elasticity and Hooke's law. This phase is related to critical thinking indicators. analyze and evaluate, where participants learn to understand concept, analyze and evaluate.

After the completion of the project, the syntax evaluation demonstrated that participants' experiences generated meaningful conclusions and reflective activities, which are closely related to the evaluation and inference indicators of critical thinking. The Project-Based Learning (PjBL) model was found to enhance specific aspects of critical thinking skills, as it encourages learners to engage with authentic, problem-based contexts that involve exploratory, collaborative, and reflective processes. Furthermore, this model trains participants to develop independent thinking in alignment with Facione's critical thinking indicators. Through the process of project creation, participants were able to construct and refine their knowledge based on direct experiences, thereby deepening their understanding of elasticity concepts and their practical applications. Based on the findings, it was evident that the most substantial improvement in critical thinking skills occurred in the evaluation indicator, as illustrated in Figure 4.

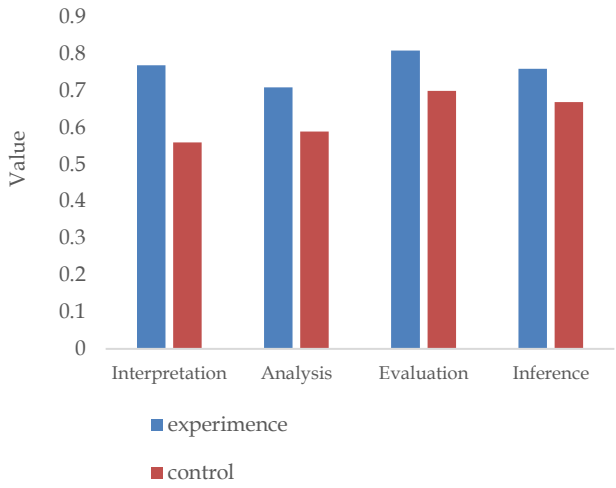

Figure 4. Results of the n-gain test of students' critical thinking skills in physics on the topic of elasticity and Hooke's law.

The N-Gain value is classified as high in the evaluation indicator, namely 0,81 in the experimental class and 0,70 in the control class, which indicates that students experienced a significant increase in their evaluation skills after the implementation of the *project-based learning* (PjBL) model. This is related to the students' experience in direct learning, where students are involved in designing their own projects, analyzing alternative solutions and concluding the results of their own projects. In the simple bow and arrow project, simple fish arrows and catapults, students learned from their experience about the flexibility of the bowstring, if the bowstring is too flexible, the arrow cannot fly far. So it is necessary to have a bowstring with a greater restoring force and a higher modulus of elasticity so that when the arrow placed on the bowstring is pulled, the restoring force will try to return the initial position of the bowstring which causes the arrow to fly. So, through the projects they make, students understand the concept of the project they make. This good n-gain category on all critical thinking indicators shows the success of improving results by using the *project-based learning model* on students' critical thinking skills on the elasticity and Hooke's law material at SMAN 1 Terara.

The N-Gain test shows improvement critical thinking skills in the category currently until high in the experimental class. These results indicate that this *project-based learning* model is capable increase involvement active participant educate, allowing them to explore concept, complete problems independently, and develop thinking critical. This model is also relevant

to problem-based learning. Context, which makes learning more meaningful.

As research by Safriana et al (2023), participants class XI students who implement PjBL show significant increase. Group experiment get larger N-Gain value than group control. Use of projects such as arrows arc simple, demanding analysis style elastic and measurement change long rubber rope bow, making participant students can observe directly influence style to distance shoot. Findings similar findings are also supported by Kanza et al (2020), who implemented a catapult project, simple in elasticity learning. N-Gain value of participants educated on the project even reached category high, showing effectiveness high in helping participant educate understand the material.

This research is also relevant to the findings of Rahmawati & Diani (2022) which stated that the PjBL model increase critical thinking skills participant educate through a learning- based process problem real that requires taking decisions and solutions problem. Participants educate find something problem then take steps in completion the problem. In addition, a study by Walihah et al (2023) confirmed that that project activities can stimulate high-level thinking skills tall Because participant students must make design, analyze experimental data, and draw conclusions conclusion scientific.

The importance of real and contextual projects is also supported by the results of the study by Wulandari & Utami (2021) which found that that contextual project use (e.g., tools simple based elasticity) increases involvement participant educate as well as their ability to connect draft physics with everyday life. Participants educate build their own knowledge through experience. PjBL give opportunity to build understanding through a collaborative, exploratory, and reflective process. In the fish and arrow project bow, participant educate not only observe change long rubber, but also connect it with the distance shoot arrow. Similarly, the catapult project allows participant educate test how far the style elastic influence distance glide object.

Based on these factors, the *project-based learning* (PjBL) model significantly improves students' critical thinking skills through exploratory and reflective activities conducted during project design and evaluation. Previous research by Kurniawati *et al. (2021) suggests that the project-based learning* model has a positive impact on improving students' critical thinking skills. This is in line with research by Wulandari et al. (2024) which suggests that significant improvements indicate that active involvement in the learning process through projects can strengthen students' understanding of the concepts of elasticity and Hooke's law. This is visible from improvement score significant *pre-test* and *post-test* in the experimental class. Involvement active participant educate in planning, implementation, to project evaluation provides meaningful learning experiences that lead to stronger understanding.

Conclusion

Based on the results and discussion, it can be concluded that the Project-Based Learning (PjBL) model has a positive effect on students' critical thinking skills, as evidenced by the N-gain values obtained in the experimental class, with interpretation indicators at 0.77, analysis at 0.71, evaluation at 0.81, and inference at 0.76. These findings indicate that the application of PjBL is effective in improving students' critical thinking skills in the topic of elasticity and Hooke's Law, where the N-gain values are categorized as a good level of improvement. The strength of PjBL lies in its ability to actively engage students in exploring concepts and developing higher-order thinking skills through contextual and applicable project activities. Furthermore, this study provides practical implications, suggesting that future researchers employing PjBL should carefully estimate the availability of tools and materials that may be difficult to procure during project implementation. Overall, this research can serve as a reference for similar studies, particularly as an alternative solution in contexts where students' critical thinking skills are observed to be relatively low.

Acknowledment
The author would like to thank the students and teachers of SMAN 1 Terara and all parties involved in this research.

Author Contribution
Helmayani Lestari served as the lead author in this study. Her contributions included research planning, data collection, and data analysis. Aris Doyan, Jannatin 'Ardhuha, and Ahmad Harjono provided valuable guidance and direction throughout the research process.

Funding
This research was conducted without financial support from any party.

Conflict of interest
There is no conflict of interest

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