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Enhancing Understanding of Boyle's Law through the Use of Simple Teaching Aids

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Abstract

Conceptual understanding in physics is often a challenge for students, especially in abstract topics such as Boyle's Law in the kinetic theory of gases. This study aims to analyze the effect of using simple teaching aids in enhancing students' understanding of Boyle's Law. The research employed a quasi-experimental method with a one-group pretest and posttest design. The study involved 34 high school students selected through simple random sampling. Data were collected through a conceptual understanding test administered before and after the implementation of the Boyle's Law teaching aid. The results showed a significant increase in the average posttest score (78.13) compared to the pretest score (38.27), with a decrease in standard deviation from 9.59 to 4.23. The N-Gain score of 0.68 indicates that the improvement in students' understanding falls within the moderate category. These findings suggest that simple teaching aids can help bridge the gap between abstract concepts in Boyle's Law and students' concrete experiences, thereby enhancing their conceptual understanding. This indicates that the use of simple teaching aids can be an effective instructional strategy for teaching abstract physics concepts, particularly Boyle's Law.

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INTRODUCTION

Physics education often faces challenges in conveying abstract concepts that cannot be directly observed by students (Bouchée et al., 2023; Hayes & Kraemer, 2017; Tenzin et al., 2022). One such topic is the kinetic theory of gases, which explains the movement of gas particles within a confined space. This theory describes how gas properties such as pressure, volume, and temperature are interrelated within a closed system (Jauhariyah et al., 2018). However, since these concepts are microscopic and cannot be seen with the naked eye, many students struggle to intuitively grasp them (Anugrah et al., 2023; Carvalho-Silva et al., 2020; Gusmida & Islami, 2017). As a result, students tend to memorize mathematical formulas without fully understanding the essence of gas particle interactions on a microscopic scale (Nurulwati et al., 2024).

One fundamental law derived from the kinetic theory of gases, which serves as the basis for understanding gas behavior, is Boyle's Law. This principle explains the relationship between pressure and volume under specific conditions. However, in practice, many students find it difficult to comprehend how a change in one variable affects the other in a closed gas system (Aprilia, 2020). This difficulty arises from the lack of visualization tools that help students connect theory with real-world phenomena. Relying solely on mathematical approaches is often insufficient to develop a strong conceptual understanding, increasing the risk of misconceptions. Therefore, a

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more interactive learning method is needed to help students gain a deeper understanding of this law. Conventional approaches in physics education, such as lectures and the presentation of concepts through text or mathematical equations, are still widely used in many schools(Ayudha & Setyarsih, 2021; Hutasuhut & Rahmatsya, 2018; Prameswara & Pius, 2023). While these methods can be effective in delivering theoretical knowledge, they often fail to provide students with direct learning experiences. In the context of Boyle's Law, for instance, lecture-based approaches frequently fall short in illustrating how pressure changes when the volume of a confined gas system is altered (Rasagama, 2021). As a result, students may be able to solve problems mechanically but fail to grasp the concept conceptually (Basiran et al., 2021; Kang et al., 2008). This can lead to weak comprehension, which may hinder their understanding of more complex topics in the future.

To address this issue, the use of simple teaching aids can serve as an effective alternative to enhance students' understanding of Boyle's Law. Teaching aids allow students to directly observe how gas pressure changes as volume varies in a closed system (Ahmad et al., 2024; Dewi et al., 2019). By engaging students in hands-on activities using teaching aids, they can build more concrete and intuitive learning experiences (Melati & Fahkiroh, 2024; Nuai & Nurkamiden, 2022). Consequently, students' understanding is not only theoretical but also based on firsthand experiences. When students actively explore concepts using teaching aids, they tend to grasp the material more easily compared to passively receiving information (Basten & Jannah, 2024; Freeman et al., 2014). Besides improving comprehension, teaching aids can also help address common misconceptions in learning Boyle's Law. One frequent misconception is the assumption that pressure and volume always change linearly or that gases have a fixed shape like solids and liquids. By using teaching aids, students can directly observe that the relationship between pressure and volume is not linear (Celant et al., 2021), but rather exponential, as described in its mathematical equation. This experience enables students to better understand Boyle's Law and avoid incorrect interpretations. Additionally, the use of teaching aids can be combined with student-centered learning models that encourage active participation. This way, students are not only observing pressure and volume changes but are also encouraged to analyze, formulate hypotheses, and draw conclusions based on their observations.

Easily accessible and classroom-friendly teaching aids are also essential in helping students establish connections between learned concepts and observed phenomena. Several studies have shown that the use of teaching aids in physics education can enhance students' conceptual understanding. These include the use of a venturimeter teaching aid (Ahmad et al., 2024), teaching aids for vectors (Muzaky & Handhika, 2015), teaching aids for vibrations and waves (Kinasih & Mariana, 2022), and teaching aids for temperature and heat (Fitriah et al., 2020). On the other hand, the development and implementation of teaching aids based on Boyle's Law have been carried out, such as a fountain that utilizes the principle of gas pressure (Jalil et al., 2021; Pangestu & Perdana, 2023). However, these tools primarily focus on applying the concept to everyday phenomena rather than directly demonstrating the relationship between pressure and volume in Boyle's Law. This study differs in that it focuses on developing a simple teaching aid specifically designed to explicitly prove Boyle's Law through direct experimentation, thereby providing a deeper understanding of the fundamental concepts of gas pressure and volume.

This study aims to analyze the impact of using simple teaching aids in enhancing students' understanding of Boyle's Law. Specifically, it will compare students' conceptual understanding before and after the implementation of teaching aids in learning. Thus, the findings of this study are expected to provide further insights into the importance of using teaching aids in physics education and to encourage innovation in teaching abstract concepts such as the kinetic theory of gases. With the growing awareness of the need for more interactive learning approaches, the results of this study can serve as a valuable reference for educators in designing more effective teaching strategies. Additionally, this research is expected to contribute to the development of experiment-based learning media that can be applied across different educational levels. Consequently, students' understanding of abstract physics concepts can be more easily established, ultimately improving the overall quality of physics education.

METHOD

This study employs a quasi-experimental method with a one-group pretest-posttest design (Sugiyono, 2012) to analyze the effectiveness of using simple teaching aids in enhancing students' understanding of Boyle's Law. In this design, only one group of students receives the treatment, and their conceptual understanding is measured before and after the learning process using the teaching aids. The study was conducted at SMAN 1 Padang Cermin, involving 34 eleventh-grade students selected through purposive sampling. The sample selection considered the equivalence of academic ability based on students' average physics scores.

The research instruments included a conceptual understanding test and an observation sheet. The conceptual understanding test consisted of a pretest and posttest in the form of five essay questions designed to assess students' comprehension of Boyle's Law before and after the treatment. The observation sheet was used to evaluate student engagement during the learning process, covering aspects such as activeness in discussions, participation in using teaching aids, and the ability to relate experimental phenomena to Boyle's Law concepts.

During the study, a simple Boyle's Law teaching aid was used to stimulate students' conceptual understanding. The simple Boyle's Law teaching aid is illustrated in Figure 1.

Figure 1. Simple Apparatus for Boyle's Law Experiment

This study began with a preparation stage, which included the development of a lesson plan based on simple teaching aids that had been validated by experts. Following this, the implementation stage was carried out, where a pretest was administered to 34 students before the lesson began to assess their initial understanding of Boyle's Law. Subsequently, students received treatment in the form of learning with simple teaching aids designed to help them explore the relationship between pressure and gas volume in a closed system more concretely. During the learning process, observations were conducted to assess students' engagement in understanding the concept through experimental activities. After the learning session was completed, students were given a posttest using the same instrument as the pretest to evaluate changes in their understanding after the treatment. Figure 2 presents the research flow.

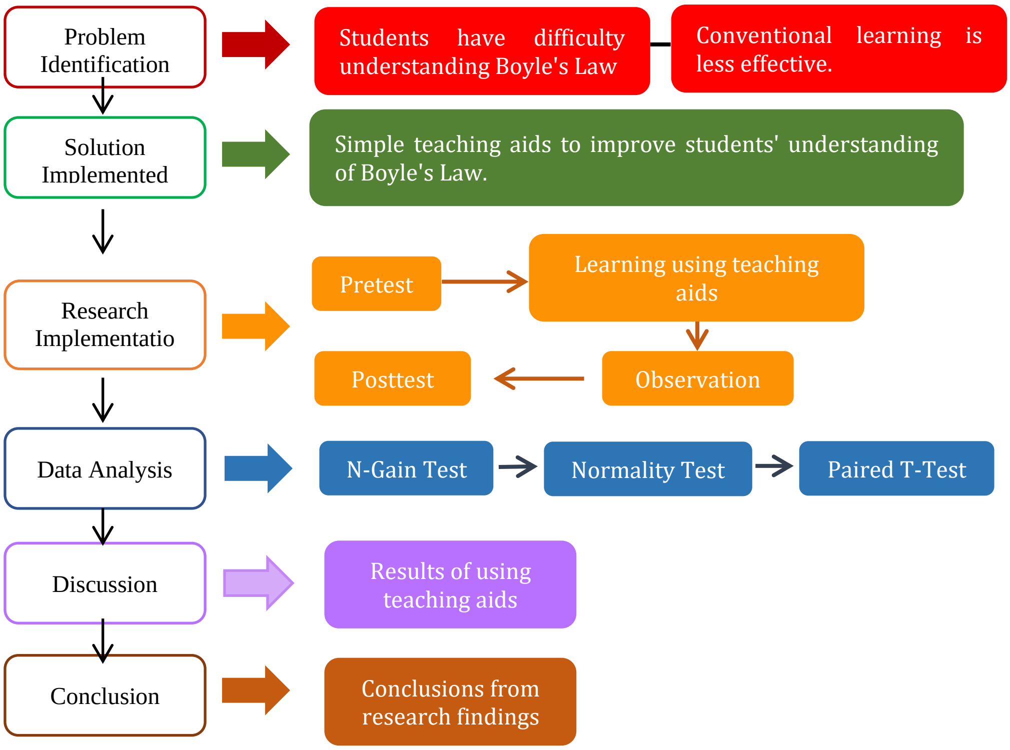

Figure 1. Simple Apparatus for Boyle's Law Experiment

The data obtained from the pretest and posttest were analyzed using the N-gain test and normality test. To test the hypothesis, a paired t-test was conducted to determine the effect of using a simple teaching aid on students' understanding before and after the lesson. The N-gain value was calculated based on the pretest and posttest results using the following formula:

$$N - Gain = \frac{posttest\ score - pretest\ score}{ideal\ maximum\ score - pretest\ score}$$

The interpretation criteria for the N-gain values are presented in Table 1.

Table 1. N-Gain Interpretation Criteria (Hake, 1998)

***N-Gain* Value**	**Interpretation Criteria**
0.71 – 1.00	High
0.41 – 0.70	Medium
0.10 – 0.40	Low

RESULTS AND DISCUSSION

The results of this study demonstrate the effect of using a simple Boyle's Law teaching aid on students' conceptual understanding. Table 2 presents the pretest and posttest results of students' conceptual understanding of Boyle's Law.

Table 2. Pretest and Posttest Data on Students' Conceptual Understanding of Boyle's Law

		Number of Students	**Max Score**	**Min Score**	**Mean**	**Std. Dev**
Experiment	*Pretest*	34	58	23	38.27	9.59
	Posttest	34	89	68	78.13	4.23

The data analysis results in Table 2 indicate a significant improvement in students' conceptual understanding after using the simple teaching aid on Boyle's Law. The average score increased from 38.27 in the pretest to 78.13 in the posttest, with the minimum score rising from 23 to 68 and the maximum score increasing from 58 to 89. Additionally, the standard deviation decreased from 9.59 to 4.23, indicating a more even distribution of students' scores after the intervention.

The improvement in students' conceptual understanding of Boyle's Law can be observed from the difference between their scores before and after using the teaching aid. The average N-gain data on students' conceptual understanding is presented in Table 3.

Table 3. N-Gain Data on Students' Conceptual Understanding

	N-gain			
	Minimum Value	Maximum Value	Mean	Interpretation
Conceptual Understanding of Boyle's Law	0.48	0.79	0.68	Medium

The N-Gain test results in Table 3 show an average value of 0.68. Based on this value, it can be concluded that there was an improvement in students' conceptual understanding of Boyle's Law, which falls into the medium category.

The results of the normality test are shown in Table 4.

Tabel 4. Normality Test Results for Conceptual Understanding Ability

		Significance	**Conclusion**
Experiment	*Pretest*	0.08	Normal
	Posttest	0.26	Normal

Based on Table 4, (sig value) > 0.05, meaning that the data sets follow a normal distribution. The normality test results confirm that the data meet the prerequisite for conducting a paired sample t-test.

Since the data are normally distributed, a paired sample t-test was conducted on the pretest and posttest data, which were derived from paired samples. The results of this test are presented in Table 5.

Table 5. Paired T-Test Results for Students' Conceptual Understanding

	Mean	**t**	**df**	**Asymp. Sig (2-tailed)**
(1)	(2)	(3)	(4)	(5)
Pretest-Posttest	-39.088	-25.129	33	0.000

The statistical analysis using the paired t-test also indicates that the use of a simple Boyle's Law teaching aid significantly enhances students' conceptual understanding, as shown by an Asymp. Sig (2-tailed) value of 0.000. Since the Asymp. Sig (2-tailed) < 0.05, it can be concluded that the use of Boyle's Law teaching aids significantly affects students' conceptual understanding.

The results of this study indicate that the use of a simple teaching aid in learning Boyle's Law can significantly enhance students' conceptual understanding. This is evident from the increase in the average pretest score from 38.27 to 78.13 in the posttest. Additionally, the minimum score, which was initially only 23, increased to 68, while the maximum score rose from 58 to 89. This improvement suggests that almost all students experienced an increase in understanding after learning with the simple teaching aid. From the perspective of standard deviation, there was a decrease from 9.59 in the pretest to 4.23 in the posttest. This reduction indicates that student learning outcomes became more homogeneous after the intervention, meaning that students' understanding of Boyle's Law became more evenly distributed compared to before using the teaching aid. In other words, the teaching aid helped reduce the gap in understanding among students, which often occurs in physics learning based on theory without direct practice.

The N-Gain test results shown in Table 3 further support the conclusion that the increase in students' understanding falls within the medium to high category, with a value of 0.68. According to Hake (1998), an N-Gain score in the range of 0.3 – 0.7 indicates that a learning intervention has a positive impact on student comprehension. In the context of this study, the simple teaching aid effectively bridged students' difficulties in understanding the relationship between pressure and gas volume, which is abstract when explained only mathematically or verbally. This finding aligns with the constructivist learning theory proposed by Piaget (1973) and Vygotsky (1978), which emphasizes that students better understand concepts when they actively construct their understanding through direct experiences. In learning Boyle's Law, the teaching aid enables students to observe the relationship between pressure and volume in a tangible way, rather than merely relying on the equation $P_1V_1 = P_2V_2$ which is often difficult to grasp without clear illustrations. Furthermore, this study aligns with Bruner's cognitive theory, which states that students learn better when they experience phenomena concretely before transitioning to symbolic representation (Nurhadi, 2020). In the context of Boyle's Law, the teaching aid allows students to directly observe how pressure changes affect gas volume before generalizing the concept into a mathematical form. From an instructional strategy perspective, this study supports the findings of (Arends, 2012), who stated that using teaching aids in science education enhances student engagement and makes abstract material easier to understand. Additionally, incorporating teaching aids into learning Boyle's Law encourages students to be more active (see Figure 2).

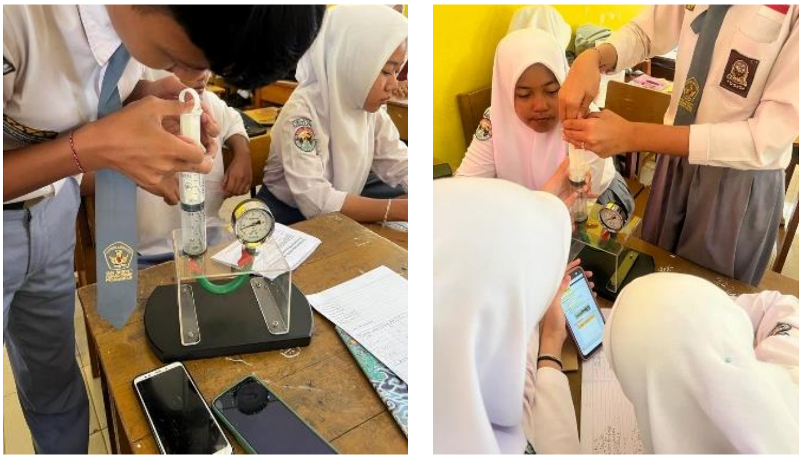

Figure 3. Students' Activities While Using the Boyle's Law Teaching Aid

During the use of the teaching aid, besides influencing students' conceptual understanding, the teaching aid also stimulates student engagement. As seen in Figure 3, students collaborate in observing and conducting experiments using the simple Boyle's Law teaching aid to examine the relationship between pressure and volume. Active students tend to be more motivated and have greater opportunities to construct their understanding, aligning with constructivist theory, which emphasizes that effective learning occurs through direct interaction with the material. A study by Basten & Jannah (2024) found that active learning methods, such as group discussions and problem-solving, significantly improve conceptual understanding compared to traditional lecture methods. Additionally, interactive and constructive activities are more effective in enhancing understanding than passive activities (Chi, 2009; Siagian, 2017). Research by Eliza et al. (2022) also found a significant positive correlation between student engagement in discussions and their understanding of physics concepts. Based on these findings, it can be concluded that student engagement is closely related to conceptual understanding.

The results of the Paired T-test indicate that sig. < 0.05, which signifies a significant difference between the pretest and posttest results. In other words, the use of a simple teaching aid has been proven to have a substantial effect on enhancing students' understanding of Boyle's Law. This finding supports the study by Rasti et al. (2024) which found that experiment-based learning positively impacts students' understanding of physics concepts. Similar findings were also reported by Hake (1998), who discovered that classes using an experiment-based approach showed greater improvements in understanding compared to those using conventional methods.

The results of this study have significant implications for physics education, particularly in teaching abstract concepts such as Boyle's Law. The improvement in students' understanding after using a simple teaching aid indicates that an experiment-based approach can be an effective strategy in science education. Teachers can integrate simple teaching aids as part of their instructional methods to help students grasp difficult concepts more easily. Moreover, the decrease in the standard deviation in the posttest results suggests that students' understanding became more uniform after the intervention, making teaching aids a potential solution to address learning gaps in the classroom. Another implication of this study is the need for further development of more interactive and technology-based teaching aids to make learning more engaging and relevant to modern advancements. Additionally, these findings provide recommendations for education policymakers to further encourage the use of experiment-based learning media in the physics curriculum to enhance the effectiveness of science education in schools. This study also opens opportunities for future research to explore the effectiveness of teaching aids in other physics concepts and to examine their long-term impact on students' retention of understanding.

LIMITATIONS

Although this study demonstrates that the use of simple teaching aids can improve students' conceptual understanding of Boyle's Law, several limitations need to be considered. First, the study was conducted on a single experimental group with a limited sample size of 34 students, making the results not yet generalizable to a broader population. Second, the research instruments used were limited to multiple-choice pretests and posttests, which may not fully capture students' in-depth conceptual understanding. Third, the duration of the intervention using the teaching aids was relatively short, so the long-term impact on students' retention of understanding could not be thoroughly analyzed. Additionally, this study focused solely on Boyle's Law within the kinetic theory of gases, without testing the effectiveness of the teaching aids on other physics concepts. Finally, the effectiveness of the teaching aids may also be influenced by teachers' skills in utilizing them and the level of student participation during learning, which can vary across different classroom implementations. Therefore, future research is recommended to involve a larger sample, use more diverse evaluation methods, examine long-term effects, and explore the effectiveness of teaching aids on other physics concepts to obtain more comprehensive findings.

CONCLUSION

Based on data analysis and discussion, it can be concluded that the use of simple teaching aids in learning Boyle's Law has proven effective in improving students' conceptual understanding. This is evidenced by the increase in average scores from 38.27 to 78.13, as well as the results of the Paired T-test, which indicated a significant difference between pretest and posttest scores. Additionally, the N-Gain score of 0.68 suggests that the improvement in students' understanding falls within the moderate to high category. These findings align with constructivist learning theory and various previous studies, which indicate that experiment-based learning and teaching aids can enhance students' conceptual understanding. Thus, this study provides an important contribution to the development of more innovative and effective teaching strategies in improving students' comprehension of physics concepts, particularly abstract ones such as Boyle's Law.

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