

Development of Closed Pipe Resonance Experiments with the Help of the Phyphox App to Improve Verbal and Numerical Representation

Annisa Nur Azizah^{1*}, Wipsar Sunu Brams Dwandaru¹, Jumadi¹

¹ Departement of Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Jl. Colombo No. 1, Karangmalang, Sleman, Yogyakarta, 55281, Indonesia.

Received: June 12, 2026

Revised: September 30, 2026

Accepted: October 12, 2026

Published: October 31, 2026

Corresponding Author:

Annisa Nur Azizah

annisa0192fmipa.2024@student.uny.ac.id

DOI: [10.29303/jppipa.v12i10.15661](https://doi.org/10.29303/jppipa.v12i10.15661)

 Open Access

© 2026 The Authors. This article is distributed under a (CC-BY License)



Abstract: This study aims to develop a closed organ pipe resonance practical model based on the Phyphox application to improve the verbal and numerical representation abilities of students at SMA N 1 Pundong. The research method used is a quasi-experiment with a one-group pretest-posttest design. The research subjects are students in classes XI B and XI D, each consisting of 36 students. The instruments used included pre-test and post-test questions, verbal representation questions, numerical representation questions, and LKPD that had been validated by experts. The validity test using Aiken's V showed that all instruments were in the high validity category. The data normality test showed that the data was normally distributed, making it suitable for analysis using the Paired Sample T-Test. The analysis results showed a significant improvement in verbal and numerical representation abilities after the treatment, indicated by a significance value (Sig.) of 0.00 (< 0.05) and a t-value that is much larger than the t-value in the table. Thus, the closed organ pipe resonance practical model based on the Phyphox application is effective in improving students' verbal and numerical representation abilities.

Keywords: Closed organ pipe resonance; Numerical representation; Phyphox; Physics experiment; Verbal representation

Introduction

Physics is a subject that most students find difficult and boring (Williams et al., 2003; Samudra et al., 2014; Wangchuk et al., 2023). This is because physics concepts are abstract and require a deep conceptual understanding to master. Physics is often linked to real-life situations, so advanced thinking skills are necessary to engage with the subject (Jamil et al., 2024; Simeon et al., 2022). Physics serves to bridge abstract concepts with concrete real-life situations that students can observe for themselves (Rinjany, 2012).

One approach to address this issue is to develop active, creative, and innovative learning methods (Karelina & Etkina, 2007). Educators can implement this approach through technology-based laboratory

experiments (Yani & Widiyatmoko, 2023; Estuhono et al., 2019). The laboratory method facilitates collaboration and active interaction among students, thereby enhancing their collaborative skills (Junita et al., 2021). Technology-based laboratory experiments are a form of contextual learning that can strengthen conceptual understanding and enhance students' interest in learning (Nuai & Nurkamiden, 2022; Agustin et al., 2026).

One physics topic requiring in-depth understanding is sound resonance in closed organ pipes (Iskandar & Pramudya, 2025; Oktapiani et al., 2024). The topic of resonance in closed organ pipes is a key concept within the field of waves and sound. Sound resonance in a closed organ pipe is the phenomenon of sound amplification that occurs when sound waves inside the pipe form a specific stationary wave pattern due to

How to Cite:

Azizah, A. N., Dwandaru, W. S. B., & Jumadi, J. (2026). Development of Closed Pipe Resonance Experiments with the Help of the Phyphox App to Improve Verbal and Numerical Representation. *Jurnal Penelitian Pendidikan IPA*, 12(10), 128-136. <https://doi.org/10.29303/jppipa.v12i10.15661>

sound reflection at the pipe's ends (Umar, 2007). Under resonance conditions, the pipe's length meets specific criteria, resulting in amplified sound amplitude. This material on resonance in closed organ pipes is often taught conventionally by teachers (Yusuf, 2018). This is due to a lack of equipment available at educational institutions. Students are only able to imagine the resonance phenomenon without engaging in activities or directly listening to the events occurring during sound resonance. Therefore, a laboratory experiment method can be a solution to the problems faced by these students.

Resonance in closed organ pipes is a physics topic well-suited for hands-on practice (Nurpratiwi et al., 2025; Aulliyah et al., 2023). This laboratory activity can provide students with engaging auditory and visual experiences (Syuhada, 2021). Teachers can integrate technology, such as smartphones, to conduct this resonance experiment. One application that can be used is Physical Phone Experiments (Phyphox) (Imtinan & Kuswanto, 2023). With the help of the Phyphox app, this experiment can be conducted in a more modern and interactive way (Pratiwi, 2023).

Phyphox is an app that allows users to perform various physics experiments using sensors in their phones, such as accelerometers, gyroscopes, and microphones (Carroll & Lincoln, 2020; Putri et al., 2025). This app is equipped with a tone generator capable of producing sound frequencies as desired (Sharma et al., 2023). These frequencies will be used to calculate the speed of the sound waves generated during the resonance of a closed organ pipe. Resonance generally occurs when a wave has the same or nearly the same frequency as the natural frequency, resulting in maximum amplitude (Harahap et al., 2024).

The development of the tool in this study is expected to improve students' verbal and numerical representations. Verbal and numerical representations are essential skills that students must possess to understand physics (Worku et al., 2026; Kohl & Finkelstein, 2006). Physics is often considered a complex and difficult-to-understand branch of science, leading students to have little interest in studying it (Amalissholeh et al., 2023). Research conducted by Kusuma et al. (2024) found that the main problems in physics learning are misconceptions, poor problem-solving skills, and a lack of contextual learning materials. In reality, physics is an enjoyable subject when taught in the right way. For example, physics can be more engaging when combined with a touch of technology. The study of physics requires a unique and engaging teaching method so that students can understand the physics concepts being taught.

Verbal representation is the ability to express concepts, phenomena, and relationships among physical

quantities through spoken or written language (Lemke, 1998). This form of representation is one type of dual representation that serves as a bridge between concrete observations and abstract concepts (Rosyadi, 2026). This ability goes beyond simply memorizing definitions; it includes accurately describing phenomena, explaining cause-and-effect relationships, using physics terminology correctly, and constructing evidence-based reasoning (Aisyah & Sudarti, 2021). In the lesson on closed-tube resonance, for example, students need to explain that resonance occurs when the frequency of the sound source matches the natural frequency of the air column, resulting in the formation of a standing wave with a sharply increasing amplitude. Such verbal explanations are crucial as indicators of conceptual understanding, since students who are skilled at calculations may not necessarily grasp the physical meaning behind them. Because the quality of an explanation depends heavily on the quality of observations, the use of the Phyphox app—which displays frequency and amplitude spectra in real time—is expected to help students formulate more accurate, data-driven verbal explanations.

In addition to verbal representation, numerical representation also plays a crucial role for students in quantitatively measuring physical parameters and precisely validating simulations against observational data (Vandegriff et al., 2024). Guzmán & Juárez (2023) also emphasize that strengthening numerical reasoning skills is key to preparing students to understand the concepts of the material being taught. Furthermore, Basriyah et al. (2020) demonstrated that numerical representation skills play a dominant role in improving academic achievement. Therefore, students' numerical representation skills must be enhanced throughout the learning process. Students can improve these numerical representations through the processes of measurement, calculation, and data analysis (Sunaryo et al., 2021). Mathematical representations can accelerate computations and enhance conceptual understanding, thereby serving to strengthen students' numerical representation skills in physics learning (Ario & Zawidski, 2024). However, a study conducted by Eliza et al. (2026) confirms that multiple representation skills—particularly numerical representation—remain a weakness for students in physics learning.

This study focuses on developing a sound resonance laboratory tool for closed organ pipes based on the Phyphox application to enhance students' verbal and numerical representations at SMA N 1 Pundong. Through a digital application-based laboratory approach, it is hoped that students will not only understand the concept of resonance theoretically but also experience it directly through the experiments conducted. In addition, through this laboratory activity,

students are expected to develop their scientific attitudes as well as their verbal and numerical skills.

Method

This study employed a quantitative approach with a quasi-experimental design (Abraham & Supriyati, 2022; Chu et al., 2019). The design used was a single-group pretest-posttest design, in which one group of students was given verbal and numerical representation tasks, which were the focus of this study.

This group was administered tests before (pretest) and after (posttest) the intervention to examine the effect of the laboratory method on the variables under study.

Table 1. Experimental design

Class	Pretest	Treatment	Posttest
XI B	p	X	P'
XI D	p	X	P'

Legend: P = pretest; P' = posttest; X = treatment involving learning through the closed-organ pipe resonance laboratory method using the Phyphox app.

The subjects of this study were students in classes XI B and XI D at SMA N 1 Pundong. Each class had 36 students. The study focused on these two groups, who participated in a resonance experiment using closed organ pipes based on the Phyphox app.

The instruments used in this study are as follows instrument validation sheet, pre-test and post-test questions, verbal representation questions, and numerical representation questions.

Instrument validation sheet: This sheet is used to validate the developed instruments. The instrument validation sheet consists of validation sheets for the pre-test and post-test questions, the worksheet validation sheet, and the validation sheets for numerical and verbal representation questions.

Pre-test and post-test questions: used to assess students' cognitive improvement regarding the material on resonance in closed organ pipes. These tests measure students' engagement during the practical learning sessions on resonance that have been conducted. This instrument was specifically developed to measure students' understanding of the physics material on sound resonance. The instrument consists of 10 multiple-choice questions distributed via a Google Form link.

Verbal representation questions: used to assess students' verbal representation skills regarding the topic of sound resonance in closed organ pipes. The verbal representation questions focus on students' ability to express physics concepts narratively, explain relationships between concepts, and present theory-

based reasons or arguments. There are 5 essay-type questions, each with a different weighting.

Numerical representation questions: used to assess students' numerical representation skills following the practical learning session on sound resonance in closed organ pipes. The research instrument in the form of numerical representation questions is used to measure students' ability to present and interpret physics concepts through symbols, numbers, and mathematical calculations. This instrument also consists of 5 essay questions, each with a different weighting. The research procedure is as follows:

Stage 1 (Pre-Test)

Before conducting the laboratory experiment, students were asked to complete a pre-test to assess their initial understanding of the concept of resonance in closed organ pipes. At this stage, the students had no prior knowledge of the phenomenon of sound resonance. In addition, students were also asked to complete verbal.

Stage 2 (Treatment)

Students conducted a resonance experiment on closed organ pipes using the Phyphox application. The experiment was carried out in groups with the guidance of student worksheets (LKPD) to facilitate exploration, discussion, and collaboration among students. Students were guided to collect and analyze data regarding the resonance parameters of the closed organ pipes obtained during the experiment.

Stage 3 (Post-Test)

After the lab, students are asked to complete the post-test again. This is to measure the effect of the lab method on the variables under study. Additionally, students are asked to complete the verbal and numerical representation questions again to assess their improvement.

The data validation analysis technique used involved analyzing the validity of the developed instrument. The analysis technique used for validity data was the Aiken coefficient calculation (Retnawati, 2016). The Aiken validity index can be expressed as follows:

$$V = \frac{\sum S}{n(C - 1)} \quad (1)$$

where V is the rater agreement index; s is the score assigned by each rater minus the lowest score in the category used; n is the number of raters; and c is the number of categories selected by the raters.

Meanwhile, the data analysis technique used in this study is the calculation of the average of pre-test and post-test scores. The scoring system used is as follows: students receive a score of 1 for a correct answer and a

score of 0 for an incorrect answer. For verbal and numerical representation data, scores were assigned according to the weighting of the questions that had been created. Both sets of data were then analyzed using Microsoft Excel to determine the students' level of engagement in the closed-organ pipe resonance lab using the Phyphox application.

For the analysis of students' verbal and numerical representations, a Paired Sample T-Test was conducted using IBM SPSS Statistics 27. This was done to test whether there were significant differences in students' verbal and numerical representations before and after the intervention. Before processing, the data was first tested for normality. The analyzed data was interpreted to determine the effect of the treatment applied in the classroom.

Result and Discussion

Validity of the Pre-Test and Post-Test Questions

Validity tests of the pre-test and post-test items were conducted to ensure that the developed items could measure students' engagement in the practical experiment on resonance in closed organ pipes using the Phyphox application. This validation was carried out by two physics teachers. The data obtained from the validity tests of the developed pre-test and post-test items are presented in Table 2.

Table 2. Validation data for the pre-test and post-test questions

Aspect	Validator 1					Validator 2				
	1	2	3	4	5	1	2	3	4	5
Content appropriateness	0	0	0	0	6	0	0	0	0	6
Item construction	0	0	0	0	5	0	0	0	0	5
Language	0	0	0	0	5	0	0	0	0	5

Content validity testing of the pre-test and post-test instruments was conducted using the Aiken V coefficient analysis technique, a method for assessing item fit based on expert evaluation. The data obtained from both validators are presented in Table 3. The Aiken V values obtained for all aspects reached 1.00, indicating that the instrument was deemed appropriate for the development objectives and capable of providing accurate data for this study.

Table 3. Results of the expert validation analysis of the pre-test and post-test instruments

Aspect	Aiken V	Category
Content appropriateness	1.00	High
Item construction	1.00	High
Language	1.00	High

Validation of Student Worksheets

The student worksheets developed in this study were also validated by two physics teachers to determine the extent to which the worksheets align with the indicators of learning objective achievement. The data obtained from the validity assessment of the student worksheets can be seen in Table 4.

Table 4. Validation data for the student worksheet

Aspect	Validator 1					Validator 2				
	1	2	3	4	5	1	2	3	4	5
Content	0	0	0	0	5	0	0	0	0	5
Construction	0	0	0	0	5	0	0	0	0	5
Appearance	0	0	0	0	5	0	0	0	0	5
Language	0	0	0	0	5	0	0	0	0	5

The validity of the Student Worksheet was analyzed using the Aiken V statistic to determine the degree of alignment between the Student Worksheet and the indicators of learning objective achievement. The results of the validity analysis of the developed Student Worksheet are presented in Table 5.

Table 5. Results of the analysis of the validation data for the student worksheet

Aspect	Aiken V	Category
Content	1.00	High
Construction	1.00	High
Appearance	1.00	High
Language	1.00	High

Validity of Verbal and Numerical Representation Items

The test instrument used to measure students' verbal and numerical representation skills was also validated by two physics teachers. This validity assessment was conducted to determine the alignment of the items with the variables measured in this study. The data obtained from the validity assessment of the verbal and numerical representation items are presented in Table 6.

Table 6. Validation data for verbal and numerical representation questions

Aspect	Validator 1					Validator 2				
	1	2	3	4	5	1	2	3	4	5
Content presented	0	0	0	0	4	0	0	0	0	4
Language	0	0	0	0	6	0	0	0	0	6
Clarity	0	0	0	0	4	0	0	0	0	4

The validity of the verbal and numerical representation items was also analyzed using the Aiken V coefficient, which was calculated by two experts. The results of the Aiken V analysis of the validity of the verbal and numerical representation items are presented in Table 7.

Table 7. Results of the validity analysis of items on verbal and numerical representation

Aspect	Aiken V	Category
Content presented	1.00	High
Language	1.00	High
Clarity	1.00	High

Pre-Test and Post-Test Results

This study was conducted in classes XI B and XI D at SMA N 1 Pundong. The study employed a quasi-experimental design, using a test administered via Google Forms as the research instrument. The test was used to determine the students' scores before and after the implementation of the learning strategies and models in classes XI B and XI D. The pre-test data obtained are presented in Table 8.

Table 8. Pre-test data

Class	Number of students	Lowest score	Highest score	Average
XI B	36	6.00	9.00	70.00
XI D	36	4.00	9.00	74.17

Table 8 shows the pre-test data before the students received the treatment. It can be observed that the lowest scores were obtained by Class XI B (6.00) and Class XI D (4.00), while the highest scores for both classes were the same, at 9.00.

The post-test results were obtained after the research subjects received the treatment in the form of learning using the closed-pipe organ resonance practical method based on the Phyphox application. The post-test results are shown in Table 9.

Table 9. Post-test data

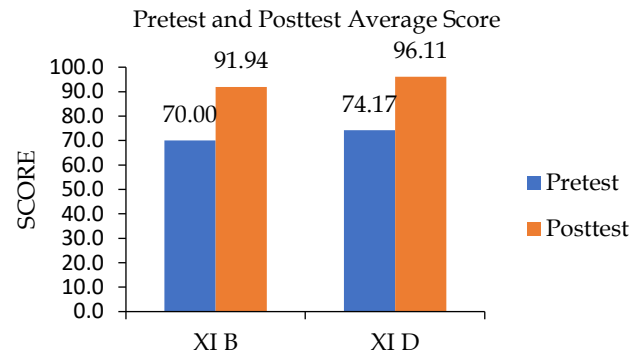
Class	Number of students	Lowest score	Highest score	Average
XI B	36	8.00	10.00	91.94
XI D	36	7.00	10.00	96.11

Table 9 shows the post-test data after the students received the intervention. It can be observed that the lowest score was 8.00 for Class XI B and 7.00 for Class XI D. The highest score obtained by both classes was the same, namely 10.00, indicating that the students answered the test perfectly. Nevertheless, the average score for Class XI D was higher than that of Class XI B.

A comparison of the pre-test and post-test scores for classes XI B and XI D at SMA N 1 Pundong is shown in Figure 1.

Figure 1 shows an improvement in student learning outcomes after receiving instruction from the teacher. Class XI B had a pre-test score of 70.00 and a post-test score of 91.94, resulting in an increase of 21.94 for Class XI B. Meanwhile, Class XI D had a pre-test score of 74.17

and a post-test score of 96.11, resulting in an increase of 21.94. Both classes showed an improvement in learning outcomes after participating in lessons using the sound resonance laboratory strategy on closed organ pipes based on the Phyphox application.

**Figure 1.** Comparison of pre-test and post-test scores*Results of Verbal Representation and Numerical Representation*

The verbal representation test was administered to the students twice—before and after the intervention—to identify any significant differences between the two. The verbal representation scores are presented in Table 10.

Table 10. Verbal representation data

Class	Highest score		Lowest score		Average	
	Before	After	Before	After	Before	After
XI B	73	85	52	63	64.89	75.42
XI D	65	80	55	70	59.89	73.89

Students were also tested on numerical representation before and after the intervention. The numerical representation scores obtained in this study are presented in Table 11.

Table 11. Numerical representation

Class	Highest score		Lowest score		Average	
	Before	After	Before	After	Before	After
XI B	74	86	55	68	64.20	77.80
XI D	68	86	58	78	62.61	81.97

Normality Test Results

A normality test was conducted before the data were analyzed using a paired-sample t-test. The results of the normality test are shown in Table 12.

Table 12. Results of the analysis of data from verbal and numerical representation instruments

Class	Sig. Verbal Representation		Sig. Numerical Representation		Description
	Before	After	Before	After	
XI B	0.15	0.15	0.64	0.47	Normally distributed
XI D	0.23	0.13	0.24	0.22	Normally distributed

In Table 12, the normality test conducted on the data from classes XI B and XI D yielded a Sig. value > 0.05 . This means that the data can be considered normally distributed and can proceed to the Paired Sample T-Test. This test is used to determine whether there are statistically significant differences in the mean scores before and after the treatment. This test was conducted four times: on the verbal representation of Class XI B, the verbal representation of Class XI D, the numerical representation of Class XI B, and the numerical representation of Class XI D.

Results of the Paired-Sample T-Test

A paired-sample t-test was conducted to determine the difference in the mean pretest and posttest scores within the same group. The test results were used to determine whether the treatment administered had a significant effect. The results of the paired-sample t-test are presented in Tables 13 and 14.

The results of the Paired Sample T-Test analysis can be seen in the t-values generated in the SPSS analysis output. To determine whether there is a significant difference between the two sets of data, the calculated t-value is compared with the critical t-value. If the calculated t-value is greater than the critical t-value, the data differ significantly. The results of the Paired Sample T-Test analysis for Class XI B are presented in Table 13.

Table 13. Paired-sample t-test for Class XI B

Representation	t	df	t _{table}	Sig.	Information
Verbal	-9.817	35	2.030	0.00	$t > t_{table}$
Numeric	-12.29	35	2.030	0.00	$t > t_{table}$

Based on the analysis results in Table 13, a Sig. (2-tailed) value of 0.000 was obtained, which is smaller than the significance level of 0.05. This indicates that there is a significant difference between the verbal and numerical representation scores in Class XI B before and after the treatment. Additionally, a significant difference between the two datasets can be seen in the values where the calculated t-value is less than the critical t-value. For verbal representation, the calculated t-value is -9.817 . The absolute value of the calculated t-value is greater than the critical t-value ($9.817 > 2.030$), indicating a significant difference between the pre- and post-intervention scores. Similarly, for the numerical representation variable, a t-calculated value of -12.29 was obtained, which is greater than the t-table value. This indicates that the implementation of the Phyphox application-based laboratory model significantly improved the verbal and numerical representation skills of Class XI B at SMA N 1 Pundong.

The results of the Paired Sample T-Test for Class XI D are presented in Table 14. Based on the results of the Paired Sample T-Test for Class XI D, a calculated t-value

of -11.11 was obtained for verbal representation, with a critical t-value of 2.030 at a 5% significance level and 35 degrees of freedom (df). The significance value (Sig.) of $0.00 < 0.05$ indicates that there is a significant difference between the pre- and post-treatment results regarding students' verbal representation. Similarly, for numerical representation, a calculated t-value of -8.850 was obtained with a critical t-value of 2.030 and a significance value of $0.00 < 0.05$, meaning there is a significant difference between the pre- and post-treatment results regarding students' numerical representation. Thus, it can be concluded that the closed-organ pipe resonance laboratory model based on the Phyphox application, as developed, significantly improved verbal and numerical representation skills in Class XI D at SMA N 1 Pundong.

Table 14. Paired-sample t-test for Class XI D

Representation	t	df	t _{table}	Sig.	Information
Verbal	-11.11	35	2.030	0.00	$t > t_{table}$
Numeric	-8.850	35	2.030	0.00	$t > t_{table}$

Overall, based on the analysis conducted, both classes showed an improvement in verbal and numerical representation after the treatment. Students demonstrated improved verbal and numerical representation after participating in the closed-organ pipe resonance laboratory experiment using the Phyphox application. This indicates that the method employed can be implemented by teachers to enhance students' verbal and numerical representation, thereby achieving the desired learning objectives.

Conclusion

Based on the results of the research and data analysis conducted, it can be concluded that the development of a closed-organ pipe resonance laboratory model using the Phyphox application has proven effective in improving students' verbal and numerical representation skills at SMA N 1 Pundong. This is evidenced by a significant increase in pre- and post-test scores for both verbal and numerical representation, as demonstrated by the results of the Paired Sample T-Test. Both classes (XI B and XI D) showed a significant improvement between pre- and post-treatment scores. The significance value (Sig. 2-tailed) obtained was also less than 0.05, indicating that the use of the Phyphox application in the laboratory experiment can help students understand the concept of closed organ pipe resonance more concretely. Additionally, the worksheets and instruments developed have been validated and meet high validity criteria, making them suitable for use in instruction.

Acknowledgments

The author would like to thank the principal of SMA N 1 Pundong, the faculty, and the students who participated in this study.

Author Contributions

Resources, conceptualization, methodology, investigation, data curation, formal analysis, writing—preparation of the original draft, writing—review and editing, A.N.A.; formal analysis, writing—preparation of the original draft, writing—review and editing, W.S.B.D.; formal analysis, writing—preparation of the original draft, writing—review and editing, J.

Funding

This research and article were funded by personal funds.

Conflicts of Interest

The data generated and analyzed during this research are not publicly available but can be obtained from the authors upon reasonable request. Conflicts of Interest: The authors declare no conflict of interest.

References

- Abraham, I., & Supriyati, Y. (2022). Desain Kuasi Eksperimen dalam Pendidikan: Literatur. *Jurnal Ilmiah Mandala Education*, 8(3). <https://doi.org/10.58258/jime.v8i3.3800>
- Agustin, M., Zubaidah, S., Susanto, H., Habiddin, H., & Bilad, M. R. (2026). Enhancing Research Skills and Student Engagement through Virtual Laboratories in Genetics Learning. *JOIV: International Journal on Informatics Visualization*, 10(5). <http://dx.doi.org/10.62527/joiv.10.5.4556>
- Aisyah, O. N., & Sudarti, S. (2021). Analisis Kemampuan Multirepresentasi Verbal dan Gambar pada Mahasiswa Pendidikan Fisika dalam Memahami Konsep Reaksi Inti Matahari. *Silampari Jurnal Pendidikan Ilmu Fisika*, 3(1), 29–38. <https://doi.org/10.31540/sjpif.v3i1.1136>
- Amalishholeh, N., Sutrio, S., Rokhmat, J., & Gunada, I. W. (2023). Analisis Kesulitan Belajar Peserta Didik pada Pembelajaran Fisika di SMAN 1 Kediri. *Empiricism Journal*, 4(2), 356–364. <https://doi.org/10.36312/ej.v4i2.1387>
- Ario, I., & Zawidski, M. (2024). *Application of Group Theory to Symmetric Structures*. Boca Raton: Taylor & Francis Group. <https://doi.org/10.1201/9781032670386>
- Aulliyah, U. A., Hakim, M. R., Dewi, S., & Suryadi, A. (2023). Analisis Pemahaman Pipa Organa Terbuka Berbantu Software Audacity pada Alat Musik Seruling Bambu. *Jurnal Fisika: Fisika Sains dan Aplikasinya*, 8(2), 78–85. <https://doi.org/10.35508/fisa.v8i2.13426>
- Basriyah, K., Sulisworo, D., Maruto, G., Toifur, M., & Rahman, N. H. A. (2020). Effects of the Flipped Classroom on Understanding the Thermodynamic Concept at High School Students. *Universal Journal of Educational Research*, 8(3 B), 51–58. <https://doi.org/10.13189/ujer.2020.081506>
- Carroll, R., & Lincoln, J. (2020). Phyphox App in the Physics Classroom. *The Physics Teacher*, 58(8), 606–607. <https://doi.org/10.1119/10.0002393>
- Chu, T.-L., Wang, J., Monrouxe, L., Sung, Y.-C., Kuo, C., Ho, L.-H., & Lin, Y.-E. (2019). The Effects of the Flipped Classroom in Teaching Evidence Based Nursing: A Quasi-Experimental Study. *PloS One*, 14(1), e0210606. <https://doi.org/10.1371/journal.pone.0210606>
- Eliza, D., Erita, Y., Yulsyofriend, Y., Hasanah, A., Anisa, N., & Dhanil, M. (2026). Development of a Mobile Role-Playing Game Application to Enhance Scientific and Cultural Literacy in Early Childhood Education. *JOIV*, 10(2), 862–871. <https://dx.doi.org/10.62527/joiv.10.2.4709>
- Estuhono, E., Festiyed, F., & Bentri, A. (2019). Preliminary Research of Developing a Research-Based Learning Model Integrated by Scientific Approach on Physics Learning in Senior High School. *Journal of Physics: Conference Series*, 1185(1), 12041. <https://doi.org/10.1088/1742-6596/1185/1/012041>
- Guzmán, D. S., & Juárez, E. C. (2023). Developing the Numeric Reasoning and Mathematical Modeling Processes in Engineering Students Using the LSEESC Methodology. *2023 IEEE Frontiers in Education Conference (FIE)*, 1–5. <https://doi.org/10.1109/FIE58773.2023.10343515>
- Harahap, R. E., Tanjung, D., & Simbolon, R. H. T. (2024). Analisis Perbandingan Respon Dinamis Pondasi Mesin Akibat Getaran Vertikal dan Horizontal Mesin pada Tanah Lunak-Sedang-Keras. *Jurnal Ilmiah Teknik Unida*, 5(1), 1–11. <https://doi.org/10.55616/jitu.v5i1.722>
- Imtinan, N., & Kuswanto, H. (2023). The Use of Phyphox Application in Physics Experiments. *JIPF*, 8(1), 183–191. <https://dx.doi.org/10.26737/jipf.v8i2.4167>
- Iskandar, F., & Pramudya, Y. (2025). Studi Faktor Kualitas Resonansi Bunyi pada Pipa Organa Tertutup Menggunakan Panjang Efektif. *JIPFRI (Jurnal Inovasi Pendidikan Fisika dan Riset Ilmiah)*, 9(1), 46–51. <https://doi.org/10.30599/jipfri.v9i1.4186>
- Jamil, M., Hafeez, F. A., & Muhammad, N. (2024). Critical Thinking Development for 21st Century: Analysis of Physics Curriculum. *Journal of Social & Organizational Matters*, 3(1), 1–10. <https://doi.org/10.56976/jsom.v3i1.45>
- Junita, A., Supriatno, B., & Purwianingsih, W. (2021). Profil Keterampilan Kolaborasi Siswa SMA pada

- Praktikum Maya Sistem Ekskresi. *Assimilation: Indonesian Journal of Biology Education*, 4(2), 50–57. <https://doi.org/10.17509/aijbe.v4i2.41480>
- Karelina, A., & Etkina, E. (2007). Acting Like a Physicist: Student Approach Study to Experimental Design. *Physical Review Special Topics – Physics Education Research*, 3(2), 20106. <https://doi.org/10.1103/PhysRevSTPER.3.020106>
- Kohl, P. B., & Finkelstein, N. D. (2006). Effects of Representation on Students Solving Physics Problems: A Fine-Grained Characterization. *Physical Review Special Topics – Physics Education Research*, 2(1), 10106. <https://doi.org/10.1103/PhysRevSTPER.2.010106>
- Kusuma, A. A. K., Wibowo, F. C., Nasbey, H., & Deta, U. A. (2024). Scientific Research on Publication of Students' Difficulties in Learning Physics: Bibliometric Analysis. *AIP Conference Proceedings*, 3116, 070027. <https://doi.org/10.1063/5.0210087>
- Lemke, J. L. (1998). Teaching All the Languages of Science: Words, Symbols, Images, and Actions. *Conference on Science Education in Barcelona*, 483–492. <https://doi.org/10.13140/2.1.4022.5608>
- Nuai, A., & Nurkamiden, S. (2022). Urgensi Kegiatan Praktikum dalam Pembelajaran Ilmu Pengetahuan Alam di Sekolah Dasar dan Menengah. *Search: Science Education Research Journal*, 1(1), 48–63. Retrieved from <https://ejurnal.iainsorong.ac.id/index.php/jaser/article/view/1240>
- Nurpratiwi, F., Hernani, H., Prima, E. C., & Septiyanto, A. (2025). Measurement of Sound Speed Using a Frequency Generator-Assisted Resonance Tube for STEM-Based Learning. *Jurnal Pendidikan Matematika dan Sains*, 13(2), 284–295. <https://doi.org/10.21831/jpms.v13i2.86417>
- Oktapiani, R. A., Hamdie, H. N. N., & Damayanti, F. E. (2024). Analisis Efisiensi Pengajaran Project Based Learning pada Praktikum Pipa Organa Sederhana. *Jurnal Pendidikan Fisika dan Sains (JPFS)*, 7(2), 136–143. <https://doi.org/10.52188/jpfs.v7i2.551>
- Pratiwi, A. D. (2023). *Pengembangan E-Modul Materi Gelombang Bunyi Berbasis Literasi Sains Berbantuan Aplikasi Phyphox* (Undergraduate Thesis). UIN Syarif Hidayatullah Jakarta. Retrieved from <https://repository.uinjkt.ac.id/dspace/handle/123456789/72763>
- Putri, L. R., Febrianti, K. V., & Utami, I. W. (2025). *Digitalisasi Eksperimen Fisika: Gerak Harmonik Sederhana Berbasis Phyphox (Transform the Smartphone Into A Versatile Physics Lab)*. Makassar: Nas Media Pustaka.
- Retnawati, H. (2016). *Analisis Kuantitatif Instrumen Penelitian*. Yogyakarta: Parama Publishing.
- Rinjany, H. (2012). *Penerapan Pendekatan SETS (Science Environment Technology and Social) pada Pembelajaran Fisika pada Diklat Guru Mapel Fisika MA*. Retrieved from <https://www.academia.edu/4575766/>
- Rosyadi, A. A. P. (2026). *Dari Konkret ke Abstrak: Memunculkan Komunikasi Siswa dengan Menggunakan Manipulative Material*. UMMPress.
- Samudra, G. B., Suastra, I. W., & Suma, K. (2014). Permasalahan-Permasalahan yang Dihadapi Siswa SMA di Kota Singaraja dalam Mempelajari Fisika. *Jurnal Pendidikan dan Pembelajaran IPA Indonesia*, 4(1). Retrieved from https://ejournal-pasca.undiksha.ac.id/index.php/jurnal_ipa/article/view/1093
- Sharma, V., Kumar, V., & Pathak, P. (2023). A Study on Intensity of Sound Waves for Variable Frequency. *2023 International Conference on Device Intelligence, Computing and Communication Technologies (DICCT)*, 208–211. Dehradun, India. <https://doi.org/10.1109/DICCT56244.2023.10110067>
- Simeon, M. I., Samsudin, M. A., & Yakob, N. (2022). Effect of Design Thinking Approach on Students' Achievement in Some Selected Physics Concepts in the Context of STEM Learning: MI. *International Journal of Technology and Design Education*, 32(1), 185–212. <https://doi.org/10.1007/s10798-020-09601-1>
- Sunaryo, S., Rustana, C. E., Raihanati, R., Khalifah, S. N., & Sugihartono, I. (2021). The Effect of the Use of Harmonic Movement PhET Interactive Simulation in Online Learning Process on Mastering the Concept of High School Students. *Journal of Physics: Conference Series*, 2019(1), 012022. <https://doi.org/10.1088/1742-6596/2019/1/012022>
- Syuhada, A. (2021). *Pengaruh Model Predict-Observe-Explain (POE) Berbantuan Multimedia Interaktif Terhadap Hasil Belajar Peserta Didik pada Konsep Gelombang Bunyi*. Jakarta: FITK UIN Syarif Hidayatullah Jakarta. Retrieved from <https://repository.uinjkt.ac.id/dspace/handle/123456789/59384>
- Umar, E. (2007). *Fisika SMA XII IPA*. Jakarta: Ganeca Exact.
- Vandegriff, E. M., Welling, D. T., Mukhopadhyay, A., Dimmock, A. P., Morley, S. K., & Lopez, R. E. (2024). Exploring Localized Geomagnetic Disturbances in Global MHD: Physics and Numerics. *Space Weather*, 22(4). <https://doi.org/10.1029/2023SW003799>
- Wangchuk, D., Wangdi, D., Tshomo, S., & Zangmo, J. (2023). Exploring Students' Perceived Difficulties of Learning Physics. *Educational Innovation and Practice*, 6. Retrieved from <https://eip.sce.edu.bt/index.php/eip/article/view/57>

- Williams, C., Stanisstreet, M., Spall, K., Boyes, E., & Dickson, D. (2003). Why Aren't Secondary Students Interested in Physics? *Physics Education*, 38(4), 324–329. <https://doi.org/10.1088/0031-9120/38/4/306>
- Worku, D. T., Ejigu, M. A., Gebremeskal, T. G., & Gogie, T. K. (2026). Assessing the Impact of Multiple Representations Based Instruction Integrated with Formative Assessment Practice on Secondary School Students' Problem-Solving Performance in Physics. *Research in Science & Technological Education*, 44(1), 224–249. <https://doi.org/10.1080/02635143.2025.2469062>
- Yani, L. P., & Widiyatmoko, A. (2023). The Effectiveness of the PhET-Assisted Creative Problem Solving Model on Students' Creative Thinking Abilities and Cognitive Learning Outcomes. *Jurnal Inovasi Pendidikan IPA*, 9(2), 146–156. <https://doi.org/10.21831/jipi.v9i2.45902>
- Yusuf, M. (2018). Upaya Meningkatkan Hasil Belajar Siswa pada Mata Pelajaran Fisika Materi Gelombang Mekanik Melalui Penerapan Pendekatan Pembelajaran Siklus Belajar Tipe Deskriptif. *JPG: Jurnal Penelitian Guru FKIP Universitas Subang*, 1(02), 240–255. Retrieved from <https://ejournal.unsub.ac.id/index.php/JPG/article/view/347>