JPPIPA 11(7) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Using the STEM Approach to Improve Students' Critical Thinking Abilities in an Integrated Flipped Classroom in Physics Learning

Miswatul Hasanah[1*], Meriza Faradilla [1], Tria Marvida[2]

[1] Program Studi Pendidikan IPA, Universitas Bina Bangsa Getsempena, Banda Aceh, Indonesia.
[2] Program Studi Pendidikan Guru Sekolah Dasar, Universitas Bina Bangsa Getsempena, Banda Aceh, Indonesia.

Received: February 13, 2025
Revised: May 29, 2025
Accepted: July 25, 2025
Published: July 31, 2025

Corresponding Author:
Miswatul Hasanah
miswatul@bbg.ac.id

DOI: 10.29303/jppipa.v11i7.10660

Abstract: This study investigates the effect of a STEM (Science, Technology, Engineering, and Mathematics) approach integrated with the flipped classroom model on students' critical thinking skills in physics learning. Using a quasi-experimental method with a nonequivalent control group design, data were collected through pretests and posttests using validated and reliable essay tests. The sample consisted of students selected through purposive sampling from two senior high schools. Results indicate a significant improvement in the critical thinking skills of students in the experimental group compared to the control group, based on N-gain and independent t-test analyses. Notably, improvements were observed in inference and explanation indicators. These findings suggest that integrating STEM with the flipped classroom model can effectively enhance students' critical thinking in physics education. This shows that students with a STEM approach have better abilities to solve problems, draw conclusions, and explain ideas.

Keywords: Critical thinking; Flipped classroom; Physics learning; STEM

Introduction

Critical thinking is one of the skills that every individual must have to face the competition of the 21st century. 21st century learning is characterized by skills in the 4Cs which include: communication, collaboration, critical thinking and problem solving, and creativity possessed by students.

Based on the results of the 2021 PISA (Program for International Student Assessment) score assessment, in general Indonesia experienced a decline in PISA scores, especially in literacy and mathematics skills, although the graph in the field of science appears to be constant, but if you look more closely there has been a decline again in 2021 compared to the previous 6 years. This proves that Indonesia must pay more attention to this problem.

The most recent PISA 2021 results show that Indonesian students' performance in science declined slightly compared to 2018, continuing a concerning trend in literacy and mathematics as well. This underlines the need to reform science education to strengthen reasoning and problem-solving skills.

Physics, as a science subject, requires students to not only memorize concepts but also apply them through logical reasoning and critical thinking. Yet, preliminary observations at high schools in Banda Aceh reveal that only 37% of students achieve minimum competency in physics, with many relying on rote memorization. When faced with unfamiliar problem contexts, students often struggle due to underdeveloped reasoning skills. Moreover, traditional instruction methods fail to engage Generation Z learners, who are deeply connected to digital media and expect learning experiences that align with their digital environment.

How to Cite:
Hasanah, M., Faradilla, M., & Marvida, T. (2025). Using the STEM Approach to Improve Students' Critical Thinking Abilities in an Integrated Flipped Classroom in Physics Learning. *Jurnal Penelitian Pendidikan IPA*, *11*(7), 926–933. https://doi.org/10.29303/jppipa.v11i7.10660

To address these challenges, it is essential to adopt innovative instructional models that integrate digital and contextual learning. The STEM (Science, Technology, Engineering, and Mathematics) approach offers an integrated way to connect science learning with real-world problems, promoting inquiry, creativity, and critical thinking. However, implementing STEM effectively can be time-consuming and constrained by limited classroom hours (Luthfiyani et al., 2019).

To overcome time limitations, combining STEM with the flipped classroom model provides a practical solution. The flipped classroom shifts initial instruction outside the classroom via videos and learning materials, enabling more in-class time for collaborative problem-solving and critical thinking. This synergy allows students to develop deeper understanding through guided exploration during class while preparing independently beforehand (Utami et al., 2024).

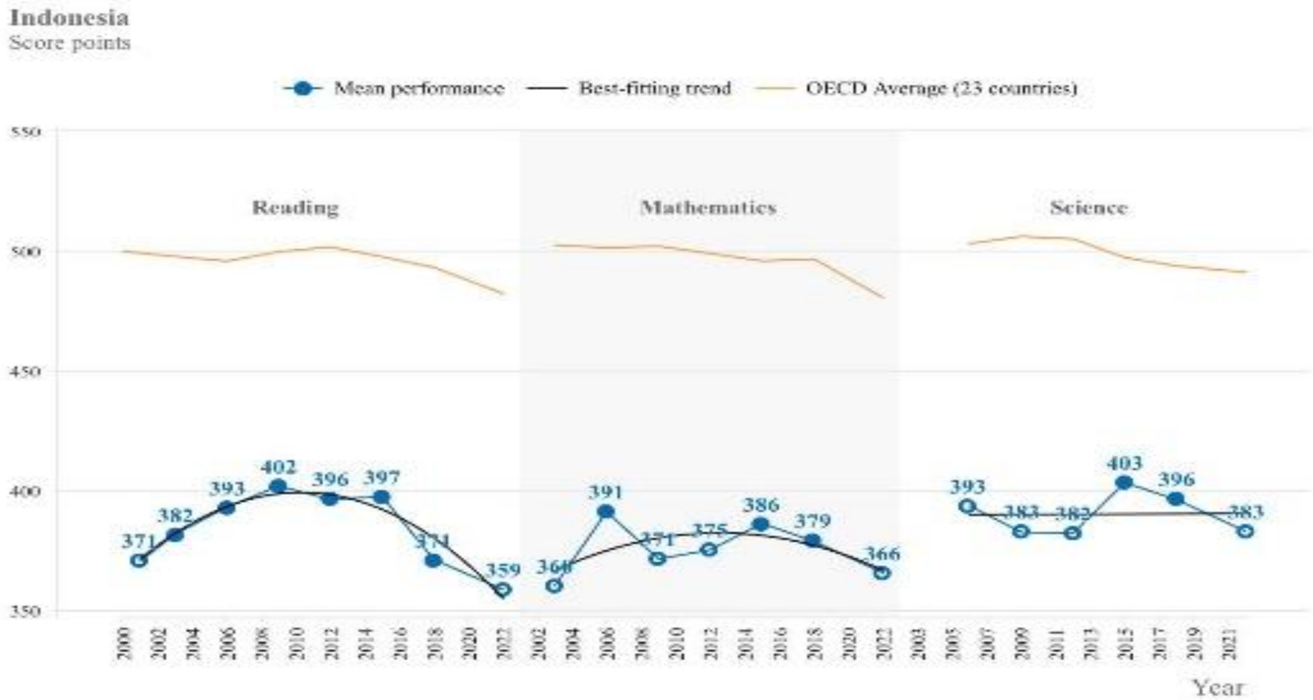

Figure 1. Indonesia PISA scores on science literacy (Source: OECD)

This study explores the novelty of integrating the STEM approach with the flipped classroom model in physics education. While each method has been shown to enhance learning outcomes individually, their combined implementation remains underexplored in the Indonesian context. Therefore, this research is important to determine whether such an integration can significantly improve students' critical thinking skills, especially in areas such as inference and explanation—while also meeting the learning preferences of today's digitally native students.

STEM is an effective way to facilitate and maintain the integration of science, technology, mathematics and engineering (Estapa & Tank, 2017). The cause of the low scientific literacy of students in Indonesia is due to a lack of textual and contextual learning. When students master scientific literacy, they will be able to understand that modern society is very dependent on technology and progress, as well as the development of science (Listiana et al., 2019). Using the STEM approach will enable the development of knowledge structures such as involvement in investigation and problem solving activities so as to improve students' critical thinking abilities (Mardiani et al., 2023). One of the shortcomings of the STEM approach is that it takes a long time to solve problems (Ritonga & Zulkarnain, 2021). Seeing the current conditions, the learning process time is too short and many students do not understand physics learning. These obstacles can be overcome by conducting learning outside school hours (Apriyanti et al., 2016). The STEM learning approach can be combined with other learning models to maximize learning outcomes (Mardiani et al., 2023). A learning model that is suitable for synergizing learning outside school hours is the flipped classroom (Hasanah & Septian, 2023). The flipped classroom helps students to study independently at home through videos and teaching materials provided by the teacher, so that students have preparation when facing problems in learning activities at school (Sinmas et al., 2019; Means et al., 2013; Alsalhi et al., 2019). The flipped classroom is effective and really has an influence on improving students' critical thinking abilities to a certain extent (Ma, 2023).

Method

This study used a quantitative approach with an experimental method, allowing objective measurement and statistical analysis to test predetermined hypotheses. The research design applied was a quasi-experimental design in the form of The Nonequivalent Control Group Design, where pretest and posttest measurements were carried out to evaluate the effects of implementing the STEM approach integrated with the Flipped Classroom model.

The population in this study included all Grade X students at SMAN 1 Sawang and SMAN 9 Banda Aceh during the 2024/2025 academic year. The sample was selected purposively, consisting of four classes: one experimental class and one control class from each school. This means there were a total of two experimental classes and two control classes involved in the study.

The instrument used to measure students' critical thinking skills was a written test in the form of essay questions. The essay test was administered before (pretest) and after (post test) the treatment. The test questions were constructed to assess higher-order thinking skills (HOTS), specifically critical thinking abilities corresponding to Bloom's Taxonomy cognitive levels C4 (analyzing), C5 (evaluating), and C6 (creating). The answers were evaluated using critical thinking indicators such as analysis, inference, explanation, and evaluation. The test items were reviewed by experts to ensure content validity, and the reliability of the test was confirmed through Cronbach's Alpha coefficient. The results of the validity test showed that all items had Pearson correlation values greater than the critical value (r_{table} = 0.361) and significance values less than 0.05, indicating that the items are valid. The reliability test using Cronbach's Alpha produced a value of 0.87, indicating that the five essay questions have high reliability. The scores obtained from this test are used as research data. Next, the research data was processed using SPSS version 20.0. The pretest-post test data on learning outcomes were analyzed to determine the N-gain, after that the differences in results were determined using parametric statistical tests, namely the independent sample t-test to see whether there was an influence based on whether there were differences in learning outcomes in the control and experimental classes.

Results and Discussion

STEM education is an educational concept that integrates various fields of science, technology, engineering and mathematics into a learning implementation concept. The STEM subject component includes sciences that study natural phenomena, including observation and measurement as a means of explaining the ever-changing nature objectively. There are several major science areas in elementary and secondary education, including physics, biology, chemistry, earth science, and space science. Technology is about human innovation, changing nature to meet human needs and desires and make life better and safer. Technology allows people to move quickly, communicate directly with people in remote areas, and find healthy food and safety equipment. Engineering is the acquisition and application of scientific, economic, social, and practical knowledge to design and build machines, devices, systems, materials, and processes that are economically beneficial to humans and environmentally friendly. In addition, mathematics is the science of patterns and relationships, which provides the language of technology, science and engineering.

Table 1. Indicators and Sub-indicators of Critical Thinking Abilities

Indicator	Sub Indicator
Interpretation	Categorize, coding, and classify
Analysis	Checking ideas and assessing arguments
Inference	Question the evidence, predicting alternatives, and take decisions/conclusions
Explanation	State the results, allow the procedure, presenting arguments, and correct yourself
Self-Regulation	Self-study and corrected himself

The results of the validation of the essay item instrument were measured using a critical thinking ability questionnaire with the 10 statement items used in the research being valid, with an average score of 0.711 with a "high" level of validity. The reliability of the item was obtained at 0.96 seen from the Spearman Brown test with the reliability level category being "very high". So, the statements used in the pretest and posttest are valid and reliable.

Table 2. Analysis of Increasing Students' Critical Thinking Abilities

School	Class	The Value of Critical Thinking Abilities		N-Gain	Category
		Pretest	Posttest		
SMAN 9	Control	68.1	77.7	0.30	Low
	Experiment	70.8	88.8	0.61	Medium
SMAN 1 Sawang	Control	67.2	76	0.26	Low
	Experiment	70.3	85.7	0.51	Medium

Based on the data in Table 2, it is evident that the improvement in students' critical thinking abilities in the experimental classes at both schools was higher than in the control classes, as indicated by the N-gain scores categorized as moderate (0.61 at SMAN 9 and 0.51 at SMAN 1 Sawang), while the control classes remained in the low category. This suggests that the implementation of the STEM-based flipped classroom model had a positive impact on enhancing students' critical thinking skills. This approach allows students to study the material independently through videos or digital resources before class, enabling classroom time to be used for problem-solving and discussion activities that foster analysis, inference, and evaluation—key components of critical thinking. These findings are supported by Rahayu et al. (2022) who found that the STEM learning model integrated with the flipped classroom significantly improved critical thinking indicators, particularly inference and explanation. Thus, the data supports the effectiveness of this innovative learning model in the context of high school science education.

Independent Sample T-Test. The conditions that must be met before carrying out this test are that the data must be normal and homogeneous. The normality test for increasing critical thinking skills, obtained in the Shapiro-Wilk column, namely in the significance column, the significant values for the control class at SMAN 9 Banda Aceh and SMAN 1 Sawang were respectively 0.851 and 0.806, for the experimental class respectively they were 0.845 and 0.938, indicating that these values were greater than 0.851, 0.806, 0.845, 0.938 > 0.05. So, it can be concluded that the data on increasing critical thinking skills in the control class and experimental class are normally distributed.

The results of the homogeneity analysis of the Levene test to improve the critical thinking skills of students in the control and experimental classes have a significant value greater than 0.05, namely 0.598 and 0.172. This shows that the data on increasing critical thinking skills in the control class and experimental class in both schools came from the same variant (homogeneous).

After the normality and homogeneity tests are completed, the next step is to test the differences between the two samples using the independent t test using a significance level = 0.05. This test was carried out to prove that there was a significant difference in student learning outcomes between the experimental class and the control class. Hypothesis testing criteria are: If Sig. 2-tailed > 0.05 then H_0 is accepted, and H_a is rejected; If Sig. 2-tailed < 0.05 then H_a is accepted and H_0 is rejected.

The results of the hypothesis testing analysis of data on increasing students' critical thinking skills in the control class and experimental class are presented in Table 3.

Table 3. Test the Hypothesis of Increasing Students' Critical Thinking Abilities

School	Class	N	df	Sig. (2-tailed)	Conclusion
SMAN 9 Banda Aceh	Control	5	8	0.002	There is a significant difference in increasing critical thinking abilities
	Experiment	5			
SMAN 1 Sawang	Control	5	8	0.000	
	Experiment	5			

Based on Table 3, data on the increase in critical thinking abilities of students in the control class and experimental class has a two-sided significance value (Sig. 2-tailed) smaller than 0.05, namely 0.002 and 0.000, meaning that the increase in the critical thinking abilities of students in the control and experimental classes is that there is a significant difference, so the learning outcomes Ha are accepted and H0 is rejected. There are differences in learning outcomes between students who are taught using the flipped classroom integrated STEM approach and learning without the flipped classroom integrated STEM approach. These differences in learning outcomes indicate the influence caused by using the integrated flipped classroom STEM approach.

The difference in the N-gain score or increase in learning outcomes between the control and experimental classes can be seen in Figure 2.

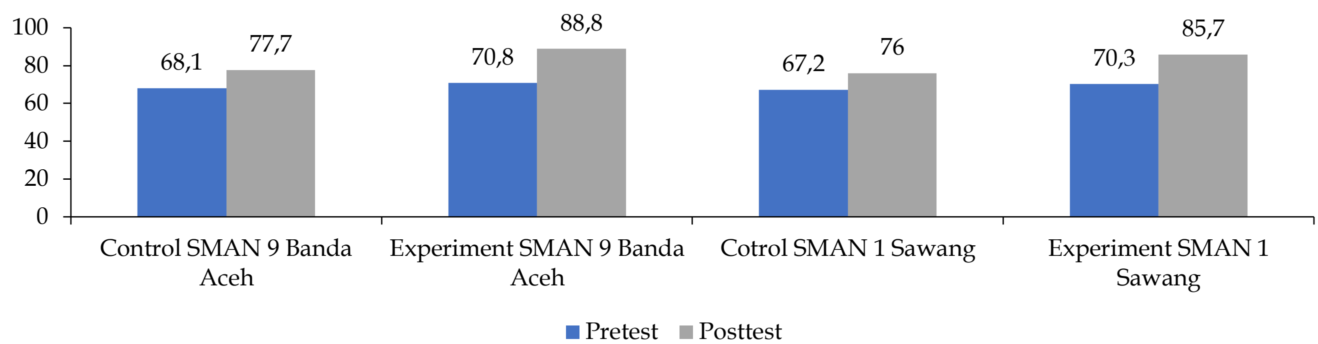

Figure 2. Graph of increasing critical thinking ability

The graph shows the results of measuring students' critical thinking abilities through pretest and posttest in four control and experimental class groups at SMAN 9 Banda Aceh and SMAN 1 Sawang. In general, each group seemed to experience an increase in scores from pretest to posttest, but this increase was more pronounced in the experimental class compared to the control class. This shows that the intervention or learning method in the experimental class has a greater positive impact than the conventional learning process in the control class.

The differences in the N-gain score for each indicator of critical thinking ability can be seen in Figure 3 below.

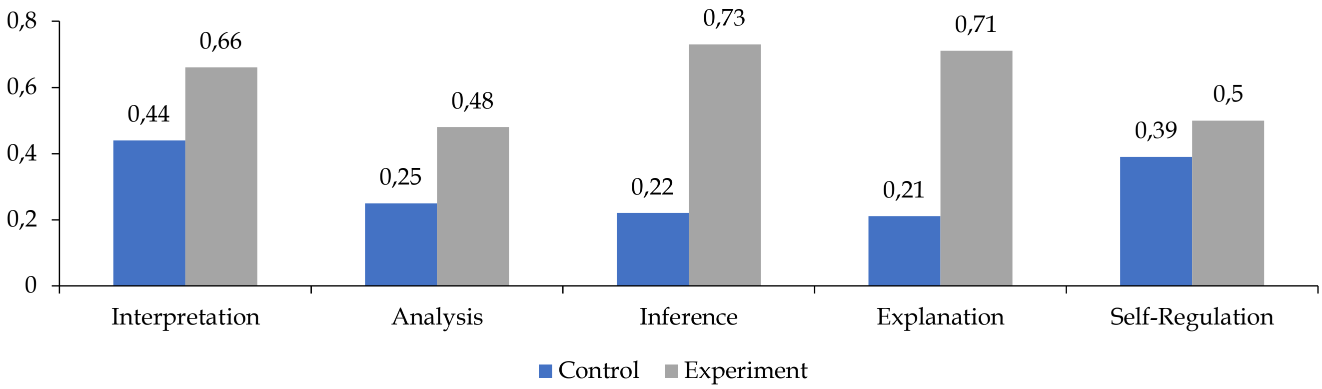

Figure 3. Gain score for each indicator of critical thinking ability

Based on Figure 3 above, there is a bar chart that compares the increase in N-gain scores (increased ability) between the control and experimental groups of students at SMAN 9 Banda Aceh. This N-gain score is measured for each indicator of critical thinking ability. There was an increase in N-gain scores in most indicators of critical thinking abilities, both in the control and experimental groups. This indicates that overall, students' critical thinking abilities have increased after being given treatment. Comparison between the control and experimental groups shows significant differences between the two groups, so it can be concluded that the treatment is effective in improving critical thinking skills on certain indicators.

The inference indicators of the experimental group were better than those of the control group. This shows that students who use the integrated flipped classroom STEM approach are better able to make logical conclusions based on the information provided. In addition, the experimental group showed significant improvement in the explanation of concepts or phenomena. This shows that students have the ability to provide a better and deeper understanding of the subject being studied. In the flipped classroom integrated STEM approach, inference and explanation indicators have increased significantly (Rahayu et al., 2022). Several aspects related to this approach contributed to this improvement. Learning that focuses more on activities that allow students to actively process data after they have learned it independently causes this increase. Many jobs in STEM require data analysis, such as experiments or case studies, which require inference skills to make conclusions from the available data (Nabila et al., 2025). Students gain better inference skills as part of science and technology-based learning (Purwasila et al., 2024).

Furthermore, the STEM approach to problem solving encourages students to participate directly in real problem-solving activities, which often do not have a single solution. This problem solving activity requires students to make explanations that are logical and based on evidence, which can improve their ability to provide clear and in-depth explanations (explanations) (Kiswari et al., 2023). This process encourages them to make appropriate conclusions from existing information.

In a flipped classroom, students are more involved in the learning process through videos, readings, and other resources before class meetings (Hasanah et al., 2021). They are better prepared to talk, analyze, and solve more difficult problems with the help of teachers and classmates when they return to the classroom. Students improve their inference and explanation skills by actively participating in these activities as they not only learn concepts but also relate them to real-world situations (Hafeez et al., 2023; Saliman et al., 2023). In a flipped classroom that is integrated with STEM, collaboration often occurs in the classroom, where students can share ideas to solve problems or explain scientific phenomena. They can expand their understanding, improve their inference skills, and improve their ability to provide more structured and evidence-based explanations by working together (Wendt & Rockinson-Szapkiw, 2015).

STEM-based learning in flipped classrooms often prioritizes critical thinking skills, which require students to make appropriate conclusions and provide in-depth explanations of experimental results or findings. Reflection on their work helps students better articulate their thought processes, which contributes to improving their inference and explanation skills (Yang, 2015).

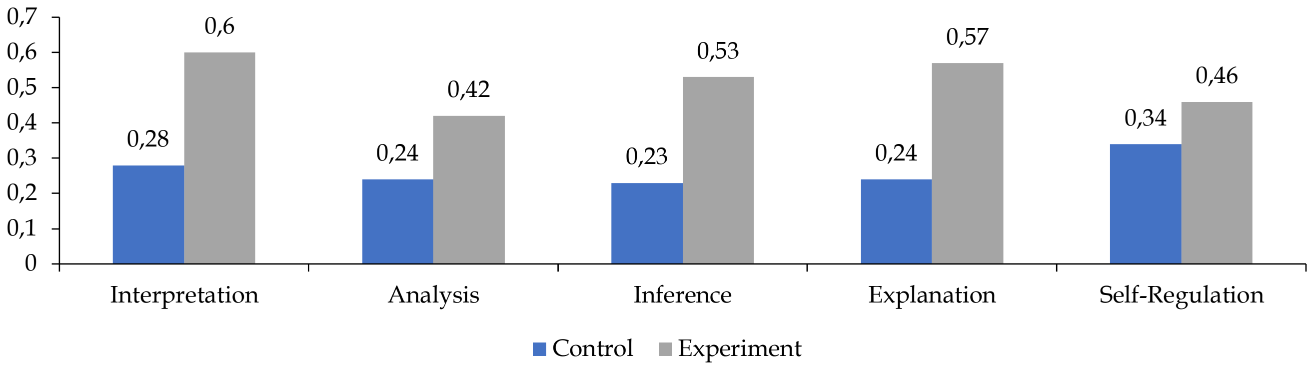

Figure 4. Gain a score for each indicator of critical thinking ability

This graph shows a comparison of the increase in critical thinking skills between the control and experimental groups at SMAN 1 Sawang. N-gain itself is a measure to find out how much students' abilities have increased after being given treatment (in this case, learning with an integrated flipped classroom STEM approach). There was an increase in critical thinking skills in both groups, both control and experimental. This is indicated by positive N-gain values in almost all indicators. The experimental group tended to have higher improvements than the control group in most indicators. This indicates that the flipped classroom integrated STEM approach has the potential to improve students' critical thinking abilities more effectively (Fidiasih et al., 2025; Suresman et al., 2023). So, based on this graph, it can be concluded that the integrated STEM flipped classroom approach has the potential to improve students' critical thinking abilities (Shodiq & Setyono, 2025).

Significant Improvement in the Experimental Group: Compared with the control group, the experimental group using the integrated flipped classroom STEM method showed more significant improvements in almost all indicators of critical thinking (Roudlo, 2020; Susiloningsih et al., 2025). This shows that this learning method is effective in improving students' critical thinking skills. In the experimental group, the analysis, inference and explanation indicators experienced the most significant improvement. This shows that students with a STEM approach have better abilities to solve problems, draw conclusions, and explain ideas.

Improvement in Interpretation and Self-Regulation Indicators: The experimental group also showed improvements in interpretation and self-regulation indicators, although not as high as the previous indicators. This shows that students better understand information and organize their thinking processes. Compared with the experimental group, the control group showed better indicators of self-regulation. This may be due to other things outside the research variables that influenced the students' ability to manage in the control group. Students in the control group started with a higher level of learning independence. They are more likely to use learning resources independently, without being driven by a particular strategy. Apart from that, the internal motivation of students in the control group to improve themselves can be the main driver in improving self-regulation.

Conclusion

The findings of this research demonstrate that the integrated STEM flipped classroom approach effectively enhances students’ critical thinking skills in physics learning. The experimental group showed a significantly greater improvement compared to the control group. This approach notably strengthened students’ ability to draw logical conclusions and explain concepts systematically. Despite its effectiveness, the implementation faced challenges such as limited instructional time and the need for careful preparation. To support wider adoption, future efforts should consider structured teacher training and targeted integration of digital tools to optimize learning. Overall, this model offers a promising strategy for improving the quality of science education and preparing students to meet future global challenges.

Acknowledgments
The authors would like to express their sincere gratitude to the schools that granted permission to conduct this research,

particularly SMA 9 Banda Aceh and Ms. Cahaya as the homeroom teacher, as well as Mr. Muzakkir, the principal of SMAN 1 Sawang. We also extend our appreciation to all related parties whose support and cooperation contributed to the successful completion of this article.

Author Contributions

Conceptualization, methodology, and validation, M.H.; formal analysis and data curation, writing-original draft preparation and visualization, M.F.; writing-review and editing, and supervision, resources, T.M. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Conflicts of Interest

No conflicts of interest.

References

Alsalhi, N. R., Eltahir, M. E., & Al-Qatawneh, S. S. (2019). The effect of Blended Learning on the Achievement of Ninth Grade Students in Science and Their Attitudes Towards Its Use. *Heliyon*, *5*(9), e02424. https://doi.org/10.1016/j.heliyon.2019.e02424

Apriyanti, Y., Nyeneng, I. D. P., & Suana, W. (2016). Pengembangan Perangkat Pembelajaran Flipped Classroom pada Materi Getaran Harmonis. *Jurnal Pembelajaran Fisika Universitas Lampung*, *5*(2), 69–79. Retrieved from https://media.neliti.com/media/publications/116432-ID-none.pdf

Estapa, A. T., & Tank, K. M. (2017). Supporting Integrated STEM in the Elementary Classroom: A Professional Development Approach Centered on an Engineering Design Challenge. *International Journal of STEM Education*, *4*(1). https://doi.org/10.1186/s40594-017-0058-3

Fidiasih, L., Triwahyuni, E., & Emyus, A. Z. (2025). Enhancing Critical Thinking and Learning Outcomes: The Impact of Differentiated Learning Strategies in Elementary School. *Jurnal Penelitian Pendidikan IPA*, *11*(4), 147–153. https://doi.org/10.29303/jppipa.v11i4.10611

Hafeez, M., Durrani, R., Saleem, A., & Tahira, F. (2023). Effects of Blended Teaching Method on Mathematics Performance of Students at Primary Level: A Case Study of District Dera Ghazi Khan, Punjab, Pakistan. *Cakrawala Pendidikan*, *42*(2), 525–538. https://doi.org/10.21831/cp.v42i2.53287

Hasanah, M., Halim, A., Safitri, R., & Yusrizal, Y. (2021). Pengaruh Model Pembelajaran Flipped Classroom Berbasis Edmodo Terhadap Hasil Belajar Peserta Didik pada Topik Gelombang Bunyi. *Jurnal Penelitian Pendidikan IPA*, *7*(SpecialIssue), 180–186. https://doi.org/10.29303/jppipa.v7ispecialissue.1061

Hasanah, M., & Septian, I. (2023). Implementation of the Flipped Classroom in Learning Sound Wave toward Students' Learning Interest. *Jurnal Pendidikan*, *24*(2), 505–515. http://dx.doi.org/10.23960/jpmipa/v23i2.pp505-515

Kiswari, L., Singgih, S., & Muhlisin, A. (2023). STEM-Based LKPD Development and Contextual Problems to Improve Explanation, Concluding, and Evaluating Skills. *Phenomenon: Jurnal Pendidikan MIPA*, *12*(2), 140–158. https://doi.org/10.21580/phen.2022.12.2.12061

Listiana, L., Abdurrahman, A., Suyatna, A., & Nuangchalerm, P. (2019). The Effect of Newtonian Dynamics STEM-Integrated Learning Strategy to Increase Scientific Literacy of Senior High School Students. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *8*(1), 43–52. https://doi.org/10.24042/jipfalbiruni.v8i1.2536

Luthfiyani, S. H., Widodo, A., & Rochintaniawati, D. (2019). Pengaruh Pembelajaran Biologi Berbasis STEM Terhadap Literasi Teknologi dan Keterampilan Pengambilan Keputusan Siswa SMA. *AIJBE*, *7260*(2), 77–82. https://doi.org/10.17509/aijbe.v2i2.19251

Ma, Y. (2023). Exploration of Flipped Classroom Approach to Enhance Critical Thinking Skills. *Heliyon*, *9*(11), e20895. https://doi.org/10.1016/j.heliyon.2023.e20895

Mardiani, A., Wilujeng, I., & Zulaikha, D. F. (2023). Exploring Teachers' Perspectives on Implementation of STEM-Inquiry Integrated with Disaster Mitigation. *JIPF (Jurnal Ilmu Pendidikan Fisika)*, *8*(1), 18. https://doi.org/10.26737/jipf.v8i1.3101

Means, B., Toyama, Y., Murphy, R., & Baki, M. (2013). The Effectiveness of Online and Blended Learning: A Meta-Analysis of the Empirical Literature. *Teachers College Record*, *115*(3). https://doi.org/10.1177/016146811311500307

Nabila, P., Mufit, F., & Novitra, F. (2025). Analysis of Students' Concept Understanding Using the STEM Integrated Cognitive Conflict Model. *Jurnal Penelitian Pendidikan IPA*, *11*(4), 435–443. https://doi.org/10.29303/jppipa.v11i4.10281

Purwasila, G. E., Pujani, N., & Sujanem, R. (2024). Model Pembelajaran Flipped Clasroom Berbasis STEM Meningkatkan Keterampilan Berfikir Kritis dan Hasil Belajar IPA Siswa. *Jurnal Pendidikan dan Pembelajaran IPA Indonesia*, *14*(1), 39–51. https://doi.org/10.23887/jppii.v14i1.75279

Rahayu, S., Abdurrahman, A., & Susana, W. (2022). Implementasi PBL Terintegrasi STEM dengan

Flipped Classroom untuk meningkatkan Kemampuan Berpikir Sistem Siswa SMA pada Topik Usaha dan Energi. *Jurnal Penelitian Pembelajaran Fisika*, *13*(2), 233–250. https://doi.org/10.26877/jp2f.v13i2.12518

Ritonga, S., & Zulkarnain, Z. (2021). Penerapan Pendekatan STEM untuk Meningkatkan Keterampilan Berpikir Kritis Peserta Didik. *Jurnal Studi Guru dan Pembelajaran*, *4*(1), 75–81. https://doi.org/10.30605/jsgp.4.1.2021.519

Roudlo, M. (2020). Kemampuan Berpikir Kritis dan Kemandirian Belajar Melalui Model Pembelajaran Flipped Classroom dengan Pendekatan STEM. *Seminar Nasional Pascasarjana 2020*, *20*, 292–297. Retrieved from https://proceeding.unnes.ac.id/snpasca/article/view/602/520

Saliman, S., Wijayanti, A. T., & Hartati, Y. (2023). Effects of Online Learning on Responsibility Character of Junior High School Students in Yogyakarta. *Cakrawala Pendidikan*, *42*(1), 189–197. https://doi.org/10.21831/cp.v42i1.53910

Shodiq, D. E., & Setyono, P. (2025). The Development of Science Learning Modules Based on PjBL- STEM to Improve Creative Thinking Skills on Environmental Pollution Materials. *Jurnal Penelitian Pendidikan IPA*, *11*(4), 41–47. https://doi.org/10.29303/jppipa.v11i4.10729

Sinmas, W. F., Sundaygara, C., & Pranata, K. B. (2019). Pengaruh PBL Berbasis Flipped Class Terhadap Prestasi Ditinjau dari Motivasi Belajar Siswa. *RAINSTEK: Jurnal Terapan Sains & Teknologi*, *1*(3), 14–20. https://doi.org/10.21067/jtst.v1i3.3730

Suresman, E., Febrianti, F. A., & Dallyono, R. (2023). Implementation of i-Spring Suite to Improve Students' Learning for Critical Thinking Skills in Natural Science. *Cakrawala Pendidikan*, *42*(2), 433–446. https://doi.org/10.21831/cp.v42i2.53646

Susiloningsih, E., Fathurohman, A., Maharani, S. D., & Fathurohman, M. F. (2025). Integration of STEM Approach in Science Education: Enhancing Students' Critical Thinking, Creativity, and Engagement in Elementary Schools in Palembang. *Jurnal Penelitian Pendidikan IPA*, *11*(4), 10–19. https://doi.org/10.29303/jppipa.v11i4.10615

Utami, U., Ghufron, A., & Setiawati, F. A. (2024). A Systematic Literature Review of Flipped Classroom: Is It Effective on Student Learning in Elementary School? *Pegem Journal of Education and Instruction*, *14*(1), 244–251. https://doi.org/10.47750/pegegog.14.01.27

Wendt, J. L., & Rockinson-Szapkiw, A. J. (2015). The Effect of Online Collaboration on Adolescent Sense of Community in Eighth-Grade Physical Science. *Journal of Science Education and Technology*, *24*(5), 671–683. https://doi.org/10.1007/s10956-015-9556-6

Yang, Y. T. C. (2015). Virtual CEOs: A Blended Approach to Digital Gaming for Enhancing Higher Order Thinking and Academic Achievement Among Vocational High School Students. *Computers and Education*, *81*, 281–295. https://doi.org/10.1016/j.compedu.2014.10.004