Berkala Ilmiah Pendidikan Fisika
https://ppjp.ulm.ac.id/journal/index.php/bipf
e-ISSN: 2549-2764 p-ISSN: 2337-604X
Vol 14 No 2 2026
DOI: 10.20527/bipf.v14i2.26012

Optimizing Deep Learning-Based STEM Instruction with PhET Simulations to Improve Science Outcomes

Nur Iftitah*, Ratih Ulfah R. Syarif, Isma Ina Daud, and Siti Irmawati
Universitas Muhammadiyah Maumere, Maumere, Indonesia
*iftyamanmeker@gmail.com

Article Info

Article history:
Received: April 26, 2026
Accepted: June 7, 2026
Published: July 25, 2026

Keywords:
Deep learning
Learning outcome
PhET simulations
STEM

This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License

© 2026 Berkala ilmiah Pendidikan Fisika

Abstract

This study aims to optimize the implementation of deep learning–based instruction integrated with a STEM approach and supported by PhET Interactive Simulations to improve students' science learning outcomes at MTs Hingalalamengi. In line with the demands of 21st-century education, the learning process emphasizes not only superficial concept mastery but also deeper understanding, critical thinking, problem-solving skills, and the ability to relate scientific concepts to real-life contexts. This study employed a quantitative approach using a pre-experimental design with a one-group pretest–posttest model. Measurements were conducted before and after the implementation to determine the effectiveness of the instructional strategy. The learning process was designed by integrating STEM principles with interactive PhET simulations, enabling students to actively engage in virtual experiments, inquiry-based exploration, and collaborative problem-solving activities. The results indicate a significant improvement in students' learning outcomes, as shown by higher posttest scores compared to pretest scores. In addition, the use of interactive simulations increased students' engagement and participation during the learning process. Students became more active in exploring concepts, conducting virtual experiments, and developing their critical thinking skills. The integration of deep learning, STEM approaches, and digital simulation media proved to create a more meaningful and student-centered learning environment. Therefore, this approach is recommended as an innovative instructional strategy to enhance the quality of science education, particularly in madrasah contexts.

To cite this article: Iftitah, N., Syarif, R. U. R., Daud, I. I., & Irmawati, S. (2026). Optimizing deep learning-based stem instruction with phet simulations to improve science outcomes. *Berkala Ilmiah Pendidikan Fisika*, *14*(2), 286-295.

INTRODUCTION

Transforming science education is essential for developing 21st-century skills in students (Mohmad, 2026; Prihatiningtyas et al., 2025). The curriculum in madrasas is not fully aligned with practice in the field, which tends to still be educator-centered (Alkahfi et al., 2024). The traditional approach results in low scientific literacy and students' ability to apply concepts to phenomena in the surrounding environment. (Putri et al., 2025; Susiloningsih et al., 2025; Zibar et al., 2025;).

The development of science and technology in the modern era has brought significant changes to the education system (Ernaningsih et al., 2025; Haq & Prasetiyo, 2025). The world of education today is required to not only emphasize mastery of theoretical knowledge but also develop critical, creative, collaborative thinking skills, and problem-

solving skills (Iftitah et al., 2023; Al Farizi et al., 2024). Therefore, the learning process needs to be designed in such a way that it can encourage students to understand concepts more deeply (deep learning) and be able to connect the knowledge learned with various phenomena that occur in everyday life.

The STEM (Science, Technology, Engineering, and Mathematics) approach is recognized as a strategic pedagogical paradigm in facilitating applicable and contextual interdisciplinary integration (Khairiyah et al., 2026; Mariam & Nurhaida, 2025; Saputri et al., 2023; Siregar et al., 2024; Sukarelawan et al., 2025). In its implementation, STEM education has a strong connection to the deep learning concept since both encourage students to actively develop conceptual understanding through exploration, reflection, and authentic learning. Through STEM education, students not only learn concepts but also develop understanding through problem identification, experimentation, problem solving, and result evaluation.

The effectiveness of this approach can be accelerated through the use of interactive simulation media such as PhET, which allows for exploratory virtual experimentation (Diab et al., 2024; Mahtari et al., 2020; Maulani et al., 2018; Ivanović, 2014). The STEM technology aspect is supported not only by the use of PhET but also by investigation-based learning experiences that help students better understand concepts. Thus, the integration of STEM and PhET simulations aligns with the principles of immersive learning by encouraging students to actively explore concepts, discover connections between theory and real-world situations, and construct meaningful knowledge. In line with this, the deep learning framework in education plays a crucial role in ensuring the achievement of substantial and holistic conceptual understanding (Santi et al., 2024; Sudarmono et al., 2025). However, there is still a discontinuity in the literature regarding the synthesis of deep learning, STEM, and digital simulations in a coherent learning framework, especially in the madrasah environment.

The novelty of this research stems from the comprehensive integration of a deep learning framework, STEM methodology, and the use of PhET digital simulations as a dynamic learning medium. This synergy is designed to transcend the boundaries of conventional learning by facilitating substantial conceptual understanding and strengthening students' applicative capacity for scientific phenomena. Specifically, this study aims to validate the implementation of the model in improving science learning outcomes at MTs Hingalalamengi and evaluate its contribution to the transformation of more progressive, technology-based pedagogical practices.

METHODS

This study employed a quantitative approach with a quasi-experimental research method. This method was chosen to determine the effect of implementing STEM-based deep learning with the help of PhET Interactive Simulations on improving student learning outcomes. The research design used was a one-group pretest–posttest design, where students were given a pretest before the learning process and a posttest after the implementation.

The research was conducted at MTs Hingalamengi, with the research subjects being students who were taking science lessons. The selection of research subjects was carried out using a purposive sampling technique, namely the selection of samples based on certain considerations that are in accordance with the research needs. In this study, all students in the sample class were involved in the STEM-based learning process. The research procedure was carried out through several stages. The first stage is the preparation stage, which includes the preparation of STEM-based learning tools, the preparation of research instruments, and the preparation of learning media in the form of PhET simulations. The second stage is the implementation stage, namely the application of STEM-based deep learning in the classroom by utilizing interactive simulations to help students understand

the concepts being studied. At this stage, students are encouraged to explore, discuss, and solve problems related to the learning material. The third stage is the evaluation stage, which is carried out through the administration of a posttest to determine the improvement in student learning outcomes after the learning process has taken place.

Prior to implementation, the research instruments were validated to ensure their validity and reliability. The learning achievement test and observation sheet were examined by expert validators consisting of physics education lecturers and subject teachers. The validation process covered aspects of content relevance, construct appropriateness, clarity of language, and suitability with the learning objectives. The validation results indicated that all instruments were categorized as valid and feasible for use in the study. In addition, the reliability test of the learning achievement instrument showed a satisfactory reliability coefficient, indicating consistency in measuring students' learning outcomes

Data collection techniques in this study included learning achievement tests, observation, and documentation. Tests were used to measure students' understanding of the material being taught, while observations were conducted to determine student activity and engagement during the learning process.

The data obtained were then analyzed using descriptive statistics to generally describe student learning outcomes. Inferential statistics were also used to determine whether there were differences in learning outcomes before and after the treatment. At this stage, paired sample t-tests were used on pretest and posttest data to determine the significance of the differences between the two results. If the significance value obtained shows $p < 0.05$, it can be concluded that there has been a significant increase in learning outcomes after the implementation of STEM-based deep learning supported by PhET Interactive Simulations. The results of this analysis also demonstrate the effectiveness of the learning model used in improving student learning outcomes.

RESULTS AND DISCUSSION

The results of the study indicate that the implementation of STEM-based deep learning assisted by PhET Interactive Simulations on temperature and heat material can improve students' conceptual understanding and cognitive skills at MTs Hingalamengi. Based on the comparison of posttest scores from both classes, there is an increase in the learning outcomes of Class VIII A students from the level of remembering to analyzing concepts, according to indicators C1–C4.

Improved learning outcomes did not occur despite the characteristics of immersive learning, which emphasizes active student engagement in the knowledge construction process. In this study, the STEM approach was not only used to integrate multiple disciplines but also combined with PhET simulations to facilitate interactive and visual exploration of concepts. Students were able to understand the relationship between temperature, heat, and energy changes more clearly through virtual simulations. This helped them grasp abstract concepts more easily. This environment supports the emergence of meaningful learning, which is the foundation of the immersive learning approach.

The results of the descriptive analysis test can be seen in Table 1.

Table 1 Learning outcomes of experimental class students

Descriptive Statistics							
	N	**Range**	**Min**	**Max**	**Sum**	**Mean**	**Std.**
Value	23	40.00	50.00	90.00	1580	68.6	10.7

Based on Table 1, the sample size (N) of students was 23. The range of scores was 40, with a minimum score of 50 and a maximum score of 90. The total score obtained by students was 1580, with an average score of 68.6. This indicates that, in general, the level of student learning outcomes is in the moderate category, as the average score is close to the standard of completeness, which is generally around 70.

Descriptive data for the control class can be seen in Table 2.

Table 2 Learning outcomes of students in the control class

	N	Range	Min	Max	Sum	Mean	Std.
Value	23	30.00	40.00	70.00	1280.0	55.6	9.1

Table 2 shows the student learning outcomes, with a sample size of 23 students. The range of scores obtained was 30, with a minimum score of 40 and a maximum score of 70. The total score for each student was 1280, with a mean score of 55.6. This mean score indicates that, in general, student learning outcomes are still in the moderate to lower category, so students' conceptual understanding still needs to be improved.

The independent sample t-test results indicated a significant difference in students' learning outcomes between the experimental and control groups ($t = 4.811$, $p < 0.05$). The mean difference of 1.389 demonstrates that students who participated in deep learning–based STEM instruction assisted by PhET simulations achieved higher learning outcomes compared to those who experienced conventional instruction.

Based on the analysis results from both experimental and control classes, the following T-test data were obtained, as given in Table 3.

Table 3 Independent t-test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Value	Equal variances assumed	.002	.966	4.811	43	.000	1.389	288.797
	Equal variances not assumed			4.799	41.965	.000	1.389	289.533

Implementation of STEM-based deep learning assisted by PhET Interactive Simulations for MTs Hingalamengi students

The implementation of STEM-based deep learning using PhET Interactive Simulations for students at MTs Hingalamengi was carried out through systematically designed learning stages to encourage active student involvement in building conceptual understanding. In the initial stages of learning, researchers linked the material to phenomena closely related to students' daily lives. This strategy aims to build prior knowledge and foster students' curiosity about the concepts to be studied, particularly those related to temperature and heat.

Student learning outcomes after the implementation of STEM-based deep learning assisted by PhET simulations showed positive results. The integration of interactive simulations into STEM learning helped students understand abstract concepts more concretely through exploration, discussion, and problem-solving activities. In addition, students were actively involved in investigating scientific phenomena, analyzing relationships among variables, and reflecting on the results of their observations, which contributed to improving their conceptual understanding and critical thinking skills.

The results of the study indicate that student learning outcomes after implementing STEM-based deep learning with the help of PhET Interactive Simulations demonstrated quite good learning outcomes. Based on the descriptive statistical analysis in Table 1, the sample size analyzed was 23 students, with a minimum score of 50 and a maximum score of 90. The range of scores obtained was 40, with a total score of 1580 and an average score of 68.6. These results indicate that, in general, students' abilities after participating in the learning process were in the fairly good category and approaching the expected mastery standard. The average score of 68.6 indicates that the majority of students were able to

understand the concepts learned after the learning process. This indicates that the implementation of the STEM-based deep learning approach can help students develop a deeper understanding of concepts. Through learning that emphasizes exploration, discussion, and problem-solving, students not only gain theoretical knowledge but also learn to relate concepts to everyday phenomena (Gao et al., 2020). This demonstrates that the applied learning approach provides opportunities for students with varying abilities to remain engaged in the learning process.

This aligns with research conducted by Sembiring (2025), which states that STEM-based science learning can improve students' critical and creative thinking skills. These improved thinking skills directly contribute to improved student learning outcomes, as students not only passively receive information but also actively engage in the analysis, problem-solving, and development of new ideas to understand the concepts being studied. In the context of science learning, critical and creative thinking skills are important factors that support students in constructing knowledge in greater depth.

However, this study differs from previous research on STEM approaches or PhET simulations. While previous research focused solely on the effectiveness of STEM approaches or PhET simulations on student learning outcomes, this study combines both into a mutually supportive learning framework. Differentiation is evident in the learning approach, which focuses not only on improving students' cognitive abilities but also on how students gain conceptual understanding through their own investigation, exploration, reflection, and analysis of scientific phenomena. Students not only observe simulations in this study; they are also directly involved in identifying problems, examining how variables relate to each other, discussing observations, and relating ideas about temperature and heat to real-world situations.

The results of this study reinforce previous arguments that combining deep learning, STEM, and PhET simulations can produce more innovative, interactive, and student-centered pedagogy. Students not only gain a better understanding of the concepts taught, but they also develop the ability to think critically, solve problems, and learn meaningfully, all crucial competencies in the 21st century. Furthermore, the use of this learning model in a madrasah context demonstrates that the use of digital technology through PhET simulations can be a strategic alternative for improving the quality of science learning, particularly in abstract topics such as temperature and heat. Therefore, this study provides both theoretical and practical contributions to the development of technology-based science learning that combines conceptual and contextual elements**.**

The findings of this study indicate that the implementation of STEM-based deep learning supported by PhET Interactive Simulations can provide a more meaningful learning experience for students (Harahap et al., 2025; Kamilah et al., 2025). Through exploration, discussion, and virtual experiments, students are encouraged to analyze observed phenomena and draw conclusions based on their observations. This learning process not only improves higher-order thinking skills but also positively impacts conceptual understanding and overall student learning outcomes (Oktariani et al., 2020; Syafitri et al., 2021).

Overall, the data analysis results indicate that the implementation of STEM-based deep learning supported by PhET simulations positively contributes to student learning outcomes (Durrani & Kataeva, 2025). Learning utilizing interactive simulations allows students to visualize physics concepts more concretely, making it easier for them to understand the relationships between the concepts being studied (Pinar et al., 2025; Soraya & Dewi, 2024). Thus, this learning approach can be an effective alternative learning strategy for improving students' conceptual understanding and learning outcomes in science (Tijani & Adeduyigbe, 2026).

There are differences in learning outcomes between students taught using a STEM-based deep learning approach assisted by PhET simulations and those taught using conventional learning

To determine whether there are differences in learning outcomes between classes taught using a STEM-based deep learning approach assisted by PhET simulations and classes taught using conventional learning, an analysis was conducted using an independent sample t-test. This test aims to compare the average learning outcomes of two different groups to determine whether the differences are statistically significant.

Based on the results of descriptive statistical analysis, the class taught using conventional learning had an average score of 55.6 with a minimum score of 40 and a maximum score of 70. Meanwhile, the class using a STEM-based deep learning approach assisted by PhET simulation had a higher average score of 68.6 with a minimum score of 50 and a maximum score of 90. This difference in average scores indicates that students who learned using a STEM-based deep learning approach obtained better learning outcomes compared to students who followed conventional learning. This occurs because the STEM approach encourages active knowledge construction (Khotimah et al., 2025; Stokes et al., 2020). Students not only receive information but are also required to analyze, evaluate, and create solutions to authentic problems. This process is in accordance with a higher cognitive level in the learning taxonomy. This results in a deeper and more lasting understanding than conventional learning, which focuses more on memorization.

Furthermore, using the independent sample t-test in Table 3, we can determine whether the difference in averages is statistically significant. If the significance value (Sig. 2-tailed) is less than 0.05, it can be concluded that there is a significant difference in learning outcomes between the two groups. This indicates that the learning approach implemented in the experimental class has a significant impact on improving student learning outcomes compared to conventional learning.

Although the analysis results indicate a significant difference in learning outcomes, the researchers also encountered several obstacles during the implementation of the learning process. One obstacle encountered was the limited technological facilities available at the school. Not all students had adequate devices to optimally access the simulation, so in some learning activities, students had to work in groups to utilize the available devices.

Furthermore, a limited internet connection also posed a barrier to the learning process utilizing technology-based simulations. On several occasions, unstable internet connections caused delays in accessing the PhET simulation, requiring additional time for learning activities. Another obstacle related to students' adaptation to the learning approach used. Some students are initially still accustomed to the conventional. Meaningful learning. This integration strengthens student-oriented pedagogy, where students are not only passively receiving information but also actively constructing knowledge through discussions, testing between variables, and solving scientific problems. In this way, the research provides an innovative contribution to the development of technology-based science learning that is more contextual and interactive and in accordance with the demands of 21st-century competencies, especially in the learning environment at Madrasah Tsanawiyah.

CONCLUSION

Based on the research conducted, it can be concluded that the implementation of STEM-based immersive learning with the aid of interactive PhET simulations improves the learning outcomes of students at MTS Hingalamamengi regarding temperature and heat. The learning model, designed through exploration, discussion, and problem-solving stages, has been proven to increase student active engagement in the learning process. Cognitive mastery of concepts is not the sole focus of this method; it also helps students improve critical thinking and understanding of ideas.

The results of the descriptive statistical analysis indicate that students in the experimental class implementing STEM-based immersive learning with the aid of PhET simulations achieved better learning outcomes than those in the control class using conventional learning. The results of the independent samples t-test, which showed a significant difference between the two groups, support this finding. Thus, it can be concluded that this learning method is more effective in improving students' understanding of ideas and their learning outcomes.

However, there are several limitations to this study. These include limited technological facilities at the school, challenges in obtaining internet access during some learning sessions, and students' recent adjustment to a learning model that demands a higher level of active participation. These limitations may impact the learning process, but they do not diminish the results.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, NI, RURS, IID, and NI; methodology, NI and RURS; formal analysis, NI, RURS, and IID; investigation, NI; data curation, NI and IID; writing—original draft preparation, NI; writing—review and editing, RURS, IID, and SI; supervision, SI; project administration, RURS. All authors have read and agreed to the published version of the manuscript.

AI DISCLOSURE STATEMENT

The authors used ChatGPT for language improvement and grammar checking during the preparation of this manuscript. All scientific content, data analysis, interpretation of results, and conclusions were developed solely by the authors. The authors reviewed and edited the generated content and take full responsibility for the final manuscript.

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to MTs Hingalamengi for providing support and facilities during the research process.

REFERENCES

Al Farizi, Z., Nurfadilah, N., Syafira Arifin, A., & Fitriani, N. (2024). Optimizing students' hots skills through ai and iot integration in digital technology learning. *Jurnal Pendidikan MIPA*, *25*(4), 1719–1737. https://doi.org/10.23960/jpmipa/v25i4.pp1719-1737

Alkahfi, A., Ernaningsih, D., & Fitriah, F. (2024). Penerapan keterampilan proses sains pada mata pelajaran ipa terhadap keaktifan peserta didik di mts muhammadiyah parumaan. *Polygon : Jurnal Ilmu Komputer Dan Ilmu Pengetahuan Alam*, *3*(1), 18–29. https://doi.org/10.62383/polygon.v3i1.337

Antonio, R. P., Cruz, B. S., Pagsanjan, E. DJ., & Castro, R. C. (2025). Using PhET simulations-integrated metacognitive argument-driven inquiry to improve students' learning outcomes in physics. *International Journal of Instruction*, *19*(1), 539–566. https://doi.org/10.29333/iji.2026.19127a

Diab, H., Daher, W., Rayan, B., Issa, N., & Rayan, A. (2024). Transforming science education in elementary schools: The power of phet simulations in enhancing student learning. *Multimodal Technologies and Interaction*, *8*(11). https://doi.org/10.3390/mti8110105

Durrani, N., & Kataeva, Z. (2025). STEM teachers' agency for gender equality in STEM education: A mixed-methods study. *International Journal of Educational Research*, *131*. https://doi.org/10.1016/j.ijer.2025.102585

Ernaningsih, D., Wahyuningsih, W., Febrianti, N. A., Amir, M. A., & Mardia, A. (2025). Integrasi pengetahuan interdipliner pada pembelajaran ipa terpadu: studi kasus pembelajaran ipa di mts muhammadiyah wuring. *Educatio, 20*(1), 195–205. https://doi.org/10.29408/edc.v20i1.29808

Fatika, A S., Joko Prayitno, H., Mu, A., Sutopo, A., & Hastuti, W. (2025). Fundamental concepts of deep learning: Principles in advancing holistic education practices journal. *Journal of Deep Learning*, *1*(2).

Gao, X., Li, P., Shen, J., & Sun, H. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. *International Journal of STEM Education*, *7*(1). https://doi.org/10.1186/s40594-020-00225-4

Harahap, F. S., Susetyarini, E., Purwanti, E., Fitri, S., Kurniaty Rukman, N., & Pohan, H. M. (2025). PhET simulation in education: A bibliometric analysis of the Scopus database. *Research and Development in Education (RaDEn), 5*(1), 555-570.https://doi.org/10.22219/raden.v5i1.4

Haq, M. D., & Prasetiyo, N. T. (2025). Deep learning sebagai pendekatan transformasional dalam pendidikan: Sebuah tinjauan literatur. *Jurnal Studi Guru Dan Pembelajaran*, *8*(3), 1826-1842. https://doi.org/10.30605/jsgp.8.3.2025.7021

Iftitah, N., Arsyad, M., & Palloan, P. (2023). The effect of problem-based learning model and self-efficacy towards creative thinking ability of class xi mipa students at sma negeri 11 takalar. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 10808–10815. https://doi.org/10.29303/jppipa.v9i12.4734

Ivanović, M. (2014). Development of media literacy – an important aspect of modern education. *Procedia - Social and Behavioral Sciences*, *149*, 438-442.

Kamilah, D. P., Sulisworo, D., & Firmansyah, J. (2025). The impact of phet simulations on conceptual understanding in high school physics: Evidence from indonesian studies. *Journal of Educational Sciences*, *9*(6), 6229–6244. https://doi.org/10.31258/jes.9.6.p.6229-6244

Khairiyah, A., Mastuang, M., & Misbah, M. (2026). Development of stem-based instructional materials to foster students' science process skills on light waves. *Tadris: Jurnal Keguruan dan Ilmu Tarbiyah*, *11*(2).

Khotimah, M. H., Wiyono, K., Sriyanti, I., & Lokal, K. (2025). Integrasi kearifan lokal dalam pendidikan STEM: Studi awal pengembangan lembar kerja peserta didik. *JIIP-Jurnal Ilmiah Ilmu Pendidikan*, *8*(5), 4634-4640.

Mahtari, S., Wati, M., Hartini, S., Misbah, M., & Dewantara, D. (2020). The effectiveness of the student worksheet with PhET simulation used scaffolding question prompt. *Journal of Physics: Conference Series*, *1422*(1), 012010.

Mariam, S., & Nurhaida, I. (2025). Analisis sentimen berbasis deep learning terhadap kesetaraan gender di bidang stem: Perspektif dan implikasinya. *Edumatic: Jurnal Pendidikan Informatika*, *9*(1), 69–78. https://doi.org/10.29408/edumatic.v9i1.29071

Maulani, R. N., Wati, M., Misbah, M., Dewantara, D., & Mahtari, S. (2018). The development of the PhET learning program's learning support worksheet. In *Proceedings of the Universitas Negeri Surabaya Physics Seminar*, *2*, 105-110.

Mohmad, R. (2026). Design thinking in education: Implications for curriculum development, classroom transaction, and learner-centered transformation. *International Journal For Multidisciplinary Research*, *18*(1).

Oktariani, M., Dahlan, D., & Waspada, I. (2020). Self regulated learning dan resiliensi akademik sebagai determinasi kemampuan berpikir kreatif. *Jurnal Ekonomi Pendidikan dan Kewirausahaan*, *8*(1), 5. https://doi.org/10.26740/jepk.v8n1.p5-16

Pinar, F. I. L., Panergayo, A. A. E., Sagcal, R. R., Acut, D. P., Roleda, L. S., & Prudente, M. S. (2025). Fostering scientific creativity in science education through scientific problem-solving approaches and STEM contexts: a meta-analysis. *Disciplinary and*

Interdisciplinary Science Education Research, *7*(1). https://doi.org/10.1186/s43031-025-00137-9

Prihatiningtyas, S., Shofiyah, N., Yunus, S. R., Ma'arif, I. B., & Putra, I. A. (2025). Enhancing science literacy through flipbook-based STEM Qur'an e-modules: a case study in Islamic boarding schools. *Humanities and Social Sciences Communications*, *12*(1). https://doi.org/10.1057/s41599-025-05054-w

Putri, P. N., Rachmadiarti, F., Purnomo, T., & Satriawan, M. (2025). Measuring scientific literacy of students' through environmental issues based on pisa 2025 science framework. *Jurnal Penelitian Pendidikan IPA*, *11*(3), 44–53. https://doi.org/10.29303/jppipa.v11i3.10413

Santi, S., Andriyaningsih, A., Seneru, W., Burmansah, B., Luwiha, L., Pratama, A. S., & Suryanadi, J. (2024). Mindful learning: Mindfulness practice matters for students on the quality of learning in the classroom. *International Journal of Science and Applied Science: Conference Series*, *8*(2), 53. https://doi.org/10.20961/ijsascs.v8i2.95098

Saputri, D. F., Wahyudi, W., Nurhayati, N., Nurussaniah, N., & Misbah, M. (2023). Development of electronic modules based on science, technology, engineering and mathematical (stem) approaches in vibration and wave courses. *Jurnal Pendidikan Fisika dan Keilmuan*, *9*(1), 53-65.

Sembiring, R. S. (2025). Pembelajaran ipa berbasis stem–pjbl: Tinjauan kritis implementasi dan integrasi teknologi deep learning untuk meningkatkan keterampilan berpikir kritis dan kreatif siswa. *Ibtida'i : Jurnal Kependidikan Dasar*, *12*(2), 233–248. https://doi.org/10.32678/ibtidai.v12i2.11783

Siregar, N. C., Gumilar, A., Amarullah, A., & Rosli, R. (2024). Stem in action: real-world applications of science, technology, engineering, and math. *Jurnal Pendidikan Matematika*, *8*(2), 493–507.

Soraya, B., & Dewi, R. S. (2024). Upaya peningkatan motivasi peserta didik kelas x - 3 pada mata pelajaran bahasa inggris dengan menggunakan media game wordwall. *Jurnal Teknologi Pendidikan*, *1*(4), 12. https://doi.org/10.47134/jtp.v1i4.89

Stokes, J. M., Yang, K., Swanson, K., Jin, W., Cubillos-Ruiz, A., Donghia, N. M., MacNair, C. R., French, S., Carfrae, L. A., Bloom-Ackerman, Z., Tran, V. M., Chiappino-Pepe, A., Badran, A. H., Andrews, I. W., Chory, E. J., Church, G. M., Brown, E. D., Jaakkola, T. S., Barzilay, R., & Collins, J. J. (2020). A deep learning approach to antibiotic discovery. *Cell*, *180*(4), 688-702.e13. https://doi.org/10.1016/j.cell.2020.01.021

Sudarmono, M. A., Hasan, H., & Halima, H. (2025). Deep learning approach in improving critical thinking skills of elementary school students. *Jurnal Penelitian Pendidikan IPA*, *11*(8), 60–70. https://doi.org/10.29303/jppipa.v11i8.11708

Sukarelawan, Moh. I., Hidayat, P., Oktova, R., Nurzannah, R. G., Putri, S. A., Mustaqim, I., Wulandari, S., & Wiranda, W. (2025). Development of learning media pop-up book of digestive system material in human grade v elementary school based on steam. *Journal of Mathematics Science and Computer Education*, *5*(1), 67. https://doi.org/10.20527/jmscedu.v5i1.14988

Susiloningsih, E., Fathurohman, A., Maharani, S. D., Fathurohman, M. F., Suratmi, & Nurani, D. C. (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

Syafitri, E., Armanto, D., & Rahmadani, E. (2021). Aksiologi kemampuan berpikir kritis. In *Journal of Science and Social Research*, *3*.

Tijani, B. E., & Adeduyigbe, A. M. (2026). Transforming science education: A systematic review of evidence-based strategies for cultivating 21st-century skills in stem education. *Journal of Research in Environmental and Science Education*, *3*(1), 8–23. https://doi.org/10.70232/jrese.v3i1.37

Zibar, C., Parisu, L., Sisi, L., & Juwairiyah, A. (2025). Pengembangan literasi sains pada siswa sekolah dasar melalui pembelajaran ipa. *Jurnal Pendidikan Multidisiplin*, *1*(1).

AUTHOR PROFILES

Nur Iftitah, MPd
iftyamanmeker@gmail.com
Physics Education Study Program, Universitas Muhammadiyah Maumere
Expertise: Learning Model
https://scholar.google.com/citations?user=aGHujp4AAAAJ&hl=en&oi=ao
Sinta: 6945546

Ratih Ulfah R.Syarif, M.Pd
ratih.rakimin.02@gmail.com
Physics Education Study Program, Universitas Muhammadiyah Maumere

Isma Ina Duat
NIM : 20240102001
ismainadaud3@gmail.com
Physics Education Study Program, Universitas Muhammadiyah Maumere

Siti Irmawati, S.Pd
irmawatisiti63@gmail.com
MTS S Hingalamamengi Kab.Lembata NTT