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Enhancing Students' Problem-Solving Ability through STEM-Integrated 5E Learning in the Context of Light Pollution

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Abstract

Problem-solving ability is an essential competency that students need to develop in order to address complex real world issues, including environmental problems. One emerging environmental issue that has received limited attention in school learning is light pollution, which results from excessive artificial lighting and can disrupt ecological balance. Integrating this phenomenon into science learning can provide a meaningful context for developing students' problem-solving ability. Therefore, this study aims to analyze the effect of Science Technology Engineering and Mathematics (STEM) integrated 5E learning on students' problem-solving ability in the context of light pollution. This study employed a quasi-experimental method with a pretest–posttest non-equivalent control group design. The participants were Phase E students at a public senior high school in Indonesia. Two classes were selected through cluster random sampling as the experimental and control groups. Data were collected using problem-solving ability tests, observation sheets, and student response questionnaires. Data were analyzed using appropriate non-parametric statistical tests and effect size calculation. The results showed a statistically significant improvement in students' problem-solving ability in the experimental group, with a moderate effect size. The experimental class also demonstrated higher learning gains compared to the control class. In addition, students responded positively to the learning activities, indicating improved understanding of environmental issues and enhanced creative problem-solving. In conclusion, STEM-integrated 5E learning is an effective approach for improving students' problem-solving ability while fostering awareness of environmental issues. This approach also highlights the potential of integrating real-world environmental contexts into science education to support more meaningful and relevant learning experiences.

Keywords: 5E learning; environmental education; light pollution; problem-solving ability; STEM education

INTRODUCTION

Problem-solving ability is an essential competency for students in addressing complex challenges in the 21st century. This ability enables individuals to identify problems, analyze alternative solutions, and determine appropriate strategies based on their knowledge and understanding (Akuba *et al.*, 2020; Julianto *et al.*, 2022). In educational contexts, problem-solving ability not only contribute to academic achievement but also support the development of critical, creative, and reflective thinking needed to respond effectively to real-world situations (Rahayu & Adistana, 2018; Septikasari & Frasandy, 2018). These competencies are increasingly important in the face of global challenges that require interdisciplinary understanding, collaboration, and adaptive thinking. Therefore, fostering students' problem-solving ability has become a central objective in contemporary science education, particularly in learning environments that emphasize meaningful, contextual, and student-centered experiences (Saldo & Walag, 2020; Utami *et al.,* 2021; Ibrahim & Rashid, 2022; Putri *et al.*, 2025).

The importance of developing problem-solving ability is also reflected in the direction of Indonesian education, which emphasizes contextual and student-centered learning to foster critical thinking and the ability to solve real life problems. Current educational practices encourage students to actively respond to global and environmental challenges through meaningful learning experiences that connect scientific concepts with authentic contexts. This orientation indicates that education should not only focus on conceptual understanding but also promote students' ability to apply knowledge in solving problems encountered in everyday life (Nuraini & Suparman, 2017; Alkair *et al.*, 2023). However, despite these educational expectations, the integration of real world environmental issues into classroom learning remains limited, particularly in relation to emerging environmental problems that require interdisciplinary approaches.

Environmental issues provide meaningful contexts for developing students' problem-solving ability because they present authentic and complex situations that require analysis and decision making. Topics such as deforestation, global warming, air pollution, and biodiversity loss are commonly discussed in science learning and demonstrate the impact of human activities on ecosystem balance. Nevertheless, the focus of environmental education is often limited to widely recognized issues, while other emerging problems receive less attention. One such issue is light pollution, which results from excessive artificial lighting and can disrupt ecological balance. Light pollution affects various biological processes, including animal migration patterns, insect activity, and human circadian rhythms. Previous studies have reported its impact on bird migration, turtle population decline, and coral reef degradation in shallow waters (Cabrera-Cruz *et al.*, 2018; Rosenberg *et al.,* 2019). In addition, disturbances caused by artificial light have broader effects on fish, amphibians, reptiles, birds, mammals, and other wildlife (Cabrera-Cruz *et al.*, 2018; Davies & Smyth, 2018). Despite its significant environmental impact, light pollution is still rarely integrated into science learning, partly due to its interdisciplinary nature, which requires the integration of multiple scientific concepts (Özyürek & Aydin, 2015; Shariff *et al.*, 2016).

Efforts to address light pollution can be categorized into technological, administrative, and educational approaches. From a technological perspective, solutions include the development of intelligent and efficient lighting systems that can automatically adjust intensity and operating time based on environmental needs. Administratively, controlling light pollution requires clear policies and regulations, such as standards for light intensity, direction of installation, and operating hours of public lighting. The implementation of dark sky zones is also considered a strategic effort to protect nocturnal ecosystems, particularly in observatory areas and wildlife habitats. However, technological and regulatory approaches alone are insufficient without educational support that promotes awareness and long term behavioral change. Education plays a crucial role in helping individuals understand the environmental consequences of excessive lighting and encouraging responsible practices in daily life (Adhitama *et al.,* 2018; Niankara & Zoungrana, 2018; Haleem *et al.*, 2022).

In the educational process, integrating light pollution into learning can provide students with opportunities to engage in authentic problem-solving processes. Through this approach, students not only learn about the negative impacts of artificial lighting on ecosystems but also develop the ability to design practical solutions, such as creating energy efficient and environmentally friendly lighting models. This process encourages students to apply scientific concepts, evaluate alternative solutions, and make informed decisions based on environmental considerations. Moreover, such learning experiences support the broader goal of education in promoting environmental sustainability and responsible citizenship (Shariff *et al*., 2016; Kaushik *et al.*, 2022). Therefore, incorporating light pollution as a learning context can enhance both conceptual understanding and problem-solving ability in a meaningful way.

The interdisciplinary characteristics of light pollution make it highly relevant to Science, Technology, Engineering, and Mathematic (STEM) learning, which integrates multiple disciplines to analyze problems and develop solutions. Previous studies have demonstrated that STEM-based learning can enhance higher order thinking and problem-solving ability (Ariyatun & Octavianelis, 2020; Lolanessa *et al.,* 2020; Alkair *et al.*, 2023). In addition, the 5E learning model consisting of Engage, Explore, Explain, Elaborate, and Evaluate stages provides a structured framework that supports active knowledge construction through inquiry-based learning (Pardede & Manurung, 2016; Uliyandari & Lubis, 2020).

Through the stages of exploration and elaboration, students are encouraged to analyze phenomena, construct explanations, and design solutions based on scientific principles. However, although previous research has highlighted the effectiveness of STEM and the 5E model in improving problem-solving ability, studies that specifically integrate STEM-based 5E learning with the context of light pollution remain limited. Furthermore, the use of light pollution as a contextual learning topic in science education is still underexplored. Based on these gaps, this study aims to analyze the effect of STEM-integrated 5E learning on students' problem-solving ability in the context of light pollution. This study is expected to contribute to the development of contextual and interdisciplinary science learning by integrating emerging environmental issues into classroom practice, while also strengthening students' ability to address real world problems.

METHOD

This study employed a quantitative approach using a quasi-experimental method with a pretest–posttest non-equivalent control group design. This design was selected because the population had been naturally organized into intact class groups, making random assignment of individual participants impractical (Creswell & Creswell, 2018). The study involved an independent variable (STEM-integrated 5E learning model) and a dependent variable (students' problem-solving ability in the context of light pollution). In addition, several control variables were considered, including students' initial knowledge, learning duration, instructional materials, evaluation methods, and the learning environment. These control variables were systematically managed to ensure that any observed differences in outcomes could be attributed primarily to the implemented learning model rather than external factors.

The control of these variables was conducted through several strategies. Students' initial knowledge was measured using pretest scores to ensure comparability between the experimental and control groups. The duration of learning was standardized across both groups by allocating the same amount of instructional time for each session. Instructional materials and evaluation instruments were designed to be equivalent in content and difficulty level, ensuring consistency in learning experiences. Furthermore, both groups were taught in similar classroom environments to minimize variations in external conditions that might influence students' performance. Through these controls, the study aimed to maintain internal validity and reduce potential bias in the research findings. In conducting research and preparing research reports, the researchers adhered to research ethics based on Rector's Decree No. 82/UN27/PP/2014, including the obligation to maintain honesty in every stage of the research, maintain objectivity and avoid all forms of falsification, and respect human subjects by minimizing risks and harms and maximizing benefits when conducting research.

The population of this study consisted of all Grade X Phase E students at a public senior high school in Indonesia. The sample comprised two classes selected using cluster random sampling based on class homogeneity. One class was assigned as the experimental group, which received STEM-integrated 5E learning, while the other served as the control group, which received conventional instruction. The research procedure began with the administration of a pretest to both groups to assess students' initial problem-solving ability. This was followed by the implementation of the respective instructional treatments over a predetermined period. At the end of the intervention, a posttest was administered to measure changes in students' problem-solving ability.

The instruments used in this study included a problem-solving ability test, observation sheets, a student response questionnaire, and a project-based assessment as supporting data. The problem-solving ability test consisted of 20 multiple-choice items designed to measure students' ability based on Polya's problem solving stages: identify problems, analyze possible solutions, and determine appropriate strategies in the context of light pollution (Polya, 1973; Arfiana & Wijaya, 2018). The instrument was developed based on relevant indicators of problem-solving ability and was subjected to expert validation to ensure content validity. Reliability testing was also conducted to ensure consistency in measurement. In addition to the test, a project-based assessment was conducted at the end of the learning process to evaluate students' ability to apply their problem-solving ability in a more authentic context. This assessment required students to design and propose solutions related to light pollution, such as creating models of environmentally friendly lighting systems. The results of this assessment were analyzed descriptively to complement the quantitative findings from the test scores and to provide a more comprehensive understanding of students' problem-solving ability.

Data on the implementation of the learning process were collected using observation sheets completed by three observers. To ensure consistency in scoring, the observers were provided with clear assessment guidelines prior to data collection. The level of agreement among observers was examined to ensure the reliability of observational data. Students' responses to the learning activities were collected using a Likert scale questionnaire designed to measure students' perceptions, engagement, and interest in the learning process. The questionnaire data were analyzed descriptively to support the interpretation of the main findings. The collected data were analyzed using both descriptive and inferential statistical techniques. Normality and homogeneity tests were conducted as preliminary analyses. Since the data did not fully meet parametric assumptions, non-parametric tests, including the Mann–Whitney test and Wilcoxon signed rank test, were applied to examine differences between groups and within groups. Effect size analysis was also conducted to determine the magnitude of the treatment effect. Through this analytical approach, the study aimed to provide a comprehensive evaluation of the effectiveness of STEM-integrated 5E learning in improving students' problem-solving ability.

RESULT AND DISCUSSION

The descriptive statistics of students' problem-solving ability in both the experimental and control groups before and after the intervention can be seen in Table 1. The pretest results show that the two groups had comparable initial mean scores, suggesting a similar baseline level of problem-solving ability. In addition, the experimental group exhibited slightly lower score variability than the control group, as reflected in its smaller standard deviation. Following the intervention, the posttest mean score of the experimental group exceeded that of the control group, indicating a greater improvement in students' problem-solving performance. These descriptive findings suggest a positive effect of the STEM-integrated 5E learning model on students' problem-solving ability.

Table 1. Descriptive statistics of students' pretest and posttest results

Group	N	Min	Max	Average	Standard Deviation
Pretest Control	31	35	95	74.52	14.34
Posttest Control	31	45	100	75.48	16.80
Experiment Pretest	31	50	100	74.35	10.47
Post-test Experiment	31	55	100	84.19	12.79

The N-gain analysis was conducted to determine the extent of improvement in students' problem-solving ability from pretest to posttest after the implementation of the learning intervention. The results provide information regarding the effectiveness of the learning process in enhancing students' understanding and problem-solving performance. A higher N-gain value indicates a greater improvement in students' abilities, while the comparison between the experimental and control groups demonstrates the relative effectiveness of STEM-integrated 5E learning compared to conventional instruction, as presented in Table 2.

Table 2. Students' N-gain values

Group	Average N-gain	Low	Moderate	High	Total
Control	-0.070	22	15	4	31
Experiment	0.276	13	8	10	31

Table 2 shows the improvement in students' learning outcomes by presenting the N-gain values for both groups. The experimental group achieved a positive average N-gain (0.276), indicating a moderate improvement in learning outcomes after the intervention. In contrast, the control group showed a negative N-gain (-0.070), suggesting that the learning process did not significantly enhance students' abilities. This difference highlights the potential effectiveness of STEM-integrated 5E learning in promoting meaningful learning gains compared to conventional approaches. To further examine the impact of the learning intervention, an analysis was also conducted on each indicator of students' problem-solving ability. This analysis aims to identify which aspects of problem-solving experienced the greatest improvement after the implementation of STEM-integrated 5E learning. The average scores for each problem-solving ability indicator in both groups are presented in Table 3.

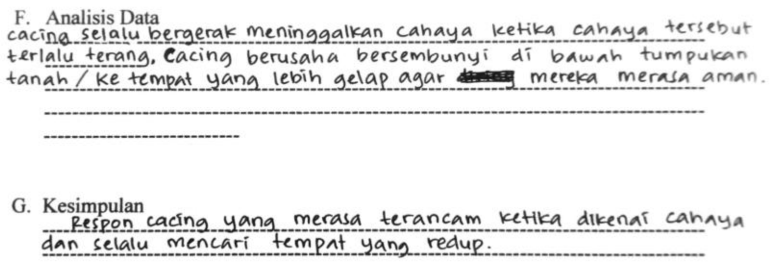
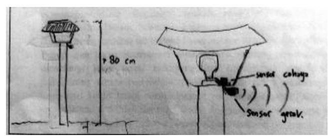
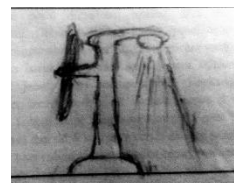
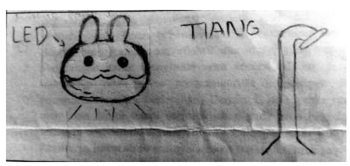
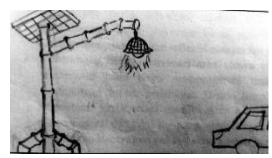
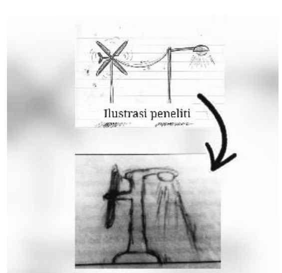
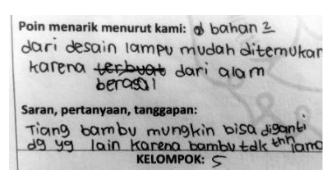
Table 3. Average score of problem-solving ability indicators

Indicator	Pretest Experiment	Posttest Experiment	Pretest Control	Posttest Control
Understanding the problem	0.884	0.922	0.876	0.870
Planning a solution	0.762	0.864	0.782	0.836
Implementing the solution	0.774	0.846	0.812	0.824
Evaluating solutions	0.860	0.967	0.863	0.803

Table 3 shows a more detailed analysis of students' problem-solving abilities by presenting the average scores for each problem-solving indicator. The experimental group demonstrated improvement across all indicators, particularly in planning and evaluating solutions, which represent higher order components of problem-solving ability. Meanwhile, the control group showed only slight improvements in several indicators and even experienced a decline in others, such as understanding the problem and evaluating solutions. These results suggest that the learning model applied in the experimental group was more effective in developing students' comprehensive problem-solving ability. In addition to measuring learning outcomes, observations of student activities were also conducted to examine how students engaged in each stage of the problem-solving process during the learning activities. The analysis of student activities provides further insight into students' participation and involvement in developing problem-solving ability throughout the implementation of the STEM-integrated 5E learning model. The results of these observations are presented in Table 4.

Table 4 shows examples of students' activities at each stage of problem-solving ability. The findings indicate that students were actively engaged in observing environmental phenomena, designing solutions, and evaluating their ideas throughout the learning process. Students began by analyzing the effects of light on animal behavior, followed by developing prototype designs for environmentally friendly lighting systems. The process also involved iterative improvement, in which students refined their designs based on feedback, discussion, and evaluation results. These activities demonstrate that the learning process facilitated the development of problem-solving ability through authentic, contextual, and collaborative experiences.

Table 4. Student activities of each stage problem-solving ability

Indicator	Student activity
Understanding the Problem	 F. Analisis Data cacing selalu bergerak meninggalkan cahaya ketika cahaya tersebut terlalu terang, cacing berusaha bersembunyi di bawah tumpukan tanah / ke tempat yang lebih gelap agar [redacted] mereka merasa aman. G. Kesimpulan Respon cacing yang merasa terancam ketika dikenai cahaya dan selalu mencari tempat yang redup.  
Planning a Solution	 
Implementing the Solution	 
Evaluating Solutions	  Poin menarik menurut kami: ~~d~~ bahan2 dari desain lampu mudah ditemukan karena ~~terbuat~~ berasal dari alam Saran, pertanyaan, tanggapan: Tiang bambu mungkin bisa diganti dg yg lain karena bambu tdk tahan lama KELOMPOK: 5

To examine whether there was a significant difference in students' problem-solving ability between the experimental and control groups following the intervention, a Mann–Whitney U test was conducted. The analysis revealed a statistically significant difference between the two groups, with an Asymp. Sig. (2-tailed) value of 0.034, which was lower than the significance level of 0.05 ($p = 0.034 < 0.05$). Therefore, the null hypothesis was rejected, indicating that students who participated in the STEM-integrated 5E learning model demonstrated significantly different levels of problem-solving ability compared to those who received conventional instruction. These findings suggest that the STEM-integrated 5E learning model had a positive effect on the development of students' problem-solving ability.

To further examine the improvement within each group, the Wilcoxon signed-rank test was also conducted. The results of this analysis indicate that the experimental group experienced a significant improvement with a strong effect size, whereas the control group did not show a statistically significant increase in problem-solving ability. The detailed results of the Wilcoxon signed rank test are presented in Table 5.

Table 5. Results of the Wilcoxon signed rank test

Group	**Sig. 2-tailed**	**Decision**	**Z**	**r**	**Interpretation**
Control	0.843	Not significant	-1.99	0.357	Moderate
Experiment	0.004	Significant	2.907	0.522	Strong

Table 5 shows the results of the Wilcoxon showed p-value lower than 0.05, which indicates a significant difference, with a strong effect that the intervention or approach given in the experiment has a positive and significant impact on the learning outcomes. Students' responses to the learning activities also support these findings. The questionnaire results indicate that most students responded positively to the implemented learning approach. A high percentage of students reported that the learning activities helped them better understand environmental issues and develop solutions through hands on experiences such as experiments and design tasks. Students also perceived the learning activities as relevant to real world situations, which contributed to increased engagement and motivation. These responses suggest that the learning model not only improved cognitive outcomes but also enhanced students' attitudes toward learning.

The responses to the learning activities, based on questionnaire results, showed that the majority of students responded positively to the implemented learning approach. In terms of problem-solving ability, 87.2% of students reported that the learning activities helped them better understand environmental issues and develop solutions through designing, testing, and evaluating ideas. Additionally, 85.2% of students gave high scores to statements related to experimental activities, design tasks, and real world applications. Furthermore, 83.6% of students indicated that the STEM concepts presented in the learning activities were relevant to real world situations and could be useful for their future learning. The findings of this study indicate that STEM-integrated 5E learning significantly improves students' problem-solving ability compared to conventional instruction. This improvement can be attributed to the characteristics of the learning model, which actively engages students in constructing knowledge through inquiry-based and contextual learning processes. The integration of real world environmental issues, such as light pollution, provides meaningful learning experiences that require students to analyze problems, generate solutions, and evaluate outcomes. These processes are essential components of problem-solving ability and align with the goals of 21st century education. Moreover, the active involvement of students in the learning process encourages deeper understanding and long term retention of knowledge (Nuraini & Suparman, 2017; Pratama *et al*., 2025).

From a theoretical perspective, the effectiveness of this learning model can be explained by constructivist learning theory, which emphasizes that knowledge is actively constructed through interaction with the environment (Ergin, 2012; Ruiz-Martín & Bybee, 2022). In this study, students were not only passive recipients of information but were actively involved in experiments, discussions, and design activities. These experiences allowed students to connect prior knowledge with new concepts and apply them in solving real world problems. The structured stages of the 5E learning model further support this process by guiding students through a systematic learning cycle, from engagement to evaluation. As a result, students develop a deeper and more meaningful understanding of the concepts being learned.

The improvement in problem-solving ability observed in this study is consistent with previous research findings. Studies reported that the 5E learning model enhances students' cognitive processes and engagement in learning (Hadi & Putriani, 2021; Salma *et al.*, 2022). The 5E model contributes to the development of critical thinking skills, which are closely related to problem-solving ability. The integration of STEM approaches within the 5E framework significantly improves student learning outcomes. These findings support the results of this study and reinforce the effectiveness of combining STEM and the 5E model in enhancing students' higher-order thinking skills (Nurwidyastuty, 2020; Ruiz-Martín & Bybee, 2022; Pramudytha *et al.,* 2025; Khasanah *et al*., 2026).

In addition to the instructional model, the use of light pollution as a contextual learning topic also played an important role in improving students' problem-solving ability. Previous studies have emphasized that integrating environmental issues into learning can enhance students' awareness and engagement (Özyürek & Aydin, 2015; Shariff *et al.,* 2016; Istiana *et al*., 2023). In this study, the context of light pollution provided students with opportunities to connect scientific concepts with real world environmental problems. This contextualization not only made learning more relevant but also encouraged students to think critically about the impact of human activities on the environment. As a result, students were more motivated to develop solutions and actively participate in the learning process (Davies & Smyth, 2018; Hadi & Putriani, 2021).

The stages of the 5E learning model further contributed to the development of students' problem-solving ability. In the Engage stage, students were introduced to real world problems related to light pollution, which helped them recognize the relevance of the topic. During the Explore stage, students conducted experiments and collected data, allowing them to construct knowledge through direct experience. In the Explain stage, students connected their findings with scientific concepts, while the Elaborate stage required them to apply their knowledge in designing solutions. Finally, the Evaluate stage encouraged reflection and improvement of their ideas. This structured learning process supports the development of analytical, creative, and evaluative thinking skills, which are essential components of problem-solving ability (Ruiz-Martín & Bybee, 2022; Pramudytha *et al.,* 2025).

Overall, the results of this study demonstrate that STEM-integrated 5E learning is an effective approach for improving students' problem-solving ability in the context of environmental issues. The combination of inquiry-based learning, interdisciplinary integration, and real world context provides a comprehensive learning experience that supports both cognitive and affective development. In addition to improving academic performance, this approach also enhances students' awareness of environmental issues and their ability to contribute to sustainable solutions. Therefore, the implementation of STEM-integrated 5E learning can be considered a valuable strategy in science education, particularly in preparing students to address complex environmental challenges in the future.

CONCLUSION

The results of this study indicate that STEM-integrated 5E learning is effective in improving students' problem-solving ability in the context of light pollution. The findings demonstrate a statistically significant improvement with a strong effect, particularly in students' ability to plan and evaluate solutions based on Polya's problem-solving stages. These results confirm that structured, inquiry-based learning integrated with STEM principles can facilitate the development of higher-order thinking skills through meaningful and contextual learning experiences. In addition, students' positive responses to the learning activities indicate that this approach enhances engagement and supports the relevance of science learning to real-world environmental issues. From a broader perspective, this study highlights the potential of integrating emerging environmental problems into science education as a strategy to strengthen students' problem-solving competence and environmental awareness. Therefore, the implementation of STEM-integrated 5E learning can contribute to the development of human resources who are capable of addressing environmental challenges, which aligns with national education goals in promoting sustainable development and responsible citizenship.

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REFERENCES

Adhitama, R. S., Kusnadi, & Supriatno, B. (2018). Kesadaran metakognitif siswa dalam pembelajaran berbasis proyek pada pokok bahasan pencemaran lingkungan. *Indonesian Journal of Biology Education*, *1*(1), 39–45.

Akuba, S. F., Purnamasari, D., & Firdaus, R. (2020). Pengaruh kemampuan penalaran, efikasi diri dan kemampuan memecahkan masalah terhadap penguasaan konsep matematika. *Jurnal Nasional Pendidikan Matematika*, *4*(1), 44–60.

Alkair, S., Ali, R., Abouhashem, A., Aledamat, R., Bhadra, J., Ahmad, Z., Sellami, A., & Al-Thani, N. J. (2023). A STEM model for engaging students in environmental sustainability programs through a problem-solving approach. *Applied Environmental Education and Communication*, *22*(1), 13–26.

Arfiana, A., & Wijaya, A. (2018). Problem solving skill of students of senior high schools and Islamic high schools in Tegal Regency in solving the problem of PISA based on Polya's stage. *Jurnal Riset Pendidikan Matematika*, *5*(2), 211–222.

Ariyatun, & Octavianelis, D. F. (2020). Pengaruh model problem based learning terintegrasi STEM terhadap kemampuan berpikir kritis siswa. *Journal of Educational Chemistry*, *2*(1), 33–39.

Cabrera-Cruz, S. A., Smolinsky, J. A., & Buler, J. J. (2018). Light pollution is greatest within migration passage areas for nocturnally-migrating birds around the world. In *Scientific Reports* (Vol. 8, Number 1). Nature Publishing Group.

Creswell, J. W., & Creswell, J. D. (2018). *Research design qualitative, quantitative, and mixed methods approaches fifth edition*. SAGE Publications, Inc.

Davies, T. W., & Smyth, T. (2018). Why artificial light at night should be a focus for global change research in the 21st century. *Global Change Biology*, *24*(3), 872–882.

Ergin, İ. (2012). Constructivist approach based 5E model and usability instructional physics. *Latin-American Journal of Physics Education*, *6*(1), 14–20.

Hadi, K., & Putriani, A. (2021). Pengaruh model pembelajaran learning cycle (5E) terhadap hasil belajar siswa pada materi klasifikasi makhluk hidup. *Bionatural*, *8*(2), 18–30.

Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, *3*, 275–285.

Ibrahim, D. S., & Rashid, A. M. (2022). Effect of project-based learning towards collaboration among students in the design and technology subject. *World Journal of Education*, *12*(3), 1–10.

Istiana, R., Herawati, D., Herniningtyas, F., Ichsan, I. Z., & Ali, A. (2023). STEM learning to improve problem solving ability on the topic of environmental education. *Jurnal Penelitian Pendidikan IPA*, *9*(3), 1202–1208.

Julianto, Wasis, Agustini, R., Suprayitno, Rukmi, A. S., Hidayati, F., & Rahmawati, E. (2022). Creative attitude in science learning model to improve creative thinking skills and positive attitude of students towards science. *International Journal of Recent Educational Research*, *3*(6), 701–717.

Kaushik, K., Nair, S., & Ahamad, A. (2022). Studying light pollution as an emerging environmental concern in India. *Journal of Urban Management*, *11*(3), 392–405.

Khasanah, A. N., Rosana, D., Wilujeng, I., Septiyanto, A., Widoretno, S., & Hudha, M. N. (2026). Mapping the integration of problem based learning, design thinking, and STEM for problem-solving skills: A bibliometric and content analysis. *International Online Journal of Education and Teaching (IOJET)*, *13*(2), 154–171.

Lolanessa, L., Kaniawati, I., & Nugraha, M. G. (2020). Pengaruh model Problem Based Learning (PBL) menggunakan pendekatan STEM dalam meningkatkan keterampilan pemecahan masalah siswa SMP. *Wahana Pendidikan Fisika*, *5*(1), 113–117.

Niankara, I., & Zoungrana, D. T. (2018). Interest in the biosphere and students environmental awareness and optimism: A global perspective. *Global Ecology and Conservation*, *16*, 1–16.

Nuraini, R., & Suparman. (2017). Deskripsi kemampuan berpikir kritis dan kreatif siswa melalui penerapan pendekatan saintifik. *Prosiding Seminar Nasional Etnomatnesia*, *6*(2), 702–707.

Nurwidyastuty, A. (2020). Pengembangan modul materi cahaya berbasis PBL4C untuk meningkatkan keterampilan berpikir kritis siswa sekolah penengah pertama. *Jurnal Didaktika Pendidikan Dasar*, *4*(3), 621–640.

Özyürek, C., & Aydin, G. (2015). Students' opinions on the light pollution application. *International Electronic Journal of Elementary Education*, *8*(1), 55–68.

Pardede, D. M., & Manurung, S. R. (2016). Pengaruh model pembelajaran inquiry training dan motivasi terhadap hasil belajar fisika siswa. *Jurnal Pendidikan Fisika*, *5*(1), 1–6.

Polya, G. (1973). *How to solve it: A new aspect of mathematical method*. Princeton University Press.

Pramudytha, A. D., Abdurrahman, & Distrik, I. W. (2025). Efektivitas model 5E terintegrasi STEM-EDP untuk meningkatkan kemampuan collaborative problem solving peserta didik SMA. *Jurnal Pendidikan Fisika*, *13*(1), 30–45.

Pratama, H., Matsun, Puspitasari, Y. D., & Maduretno, T. W. (2025). Science literacy through STEM-based project based learning model. *Jurnal Penelitian Pendidikan IPA*, *11*(7), 320–330.

Putri, D. E., Istiana, R., Herawati, D., & Zahwa, D. K. (2025). Development of a problem-based e-module on the immune system material to enhance systemic thinking skills. *Journal Of Biology Education Research (JBER)*, *6*(2), 167–175.

Rahayu, I. A. T., & Adistana, G. A. Y. P. (2018). Mengembangkan keterampilan memecahkan masalah melalui pembelajaran berdasar masalah. *Jurnal Pendidikan*, *3*(2), 86–91.

Rosenberg, Y., Doniger, T., & Levy, O. (2019). Sustainability of coral reefs are affected by ecological light pollution in the Gulf of Aqaba/Eilat. *Communications Biology*, *2*(1), 1–9.

Ruiz-Martín, H., & Bybee, R. W. (2022). The cognitive principles of learning underlying the 5E model of instruction. *International Journal of STEM Education*, *9*(21), 1–9.

Saldo, I. J. P., & Walag, A. M. P. (2020). Utilizing problem-based and project-based learning in developing students' communication and collaboration skills in physics. *American Journal of Educational Research*, *8*(5), 232–237.

Salma, I. M., Hariani, S. A., & Pujiastuti. (2022). Pengaruh model pembelajaran learning cycle (5E) berbasis STEM terhadap literasi sains dan hasil belajar siswa. *Jurnal Bioterdidik: Wahana Ekspresi Ilmiah*, *10*(2), 138–149.

Septikasari, R., & Frasandy, R. N. (2018). Keterampilan 4C abad 21 dalam pembelajaran pendidikan dasar. *Jurnal Tarbiyah Al-Awlad*, *2*, 112–122.

Shariff, N., Osman, M., Faid, M., Hamidi, Z., Sabri, S., Zainol, N., Ali, M., & Husein, N. (2016). International conference on industrial engineering, management science and application. *2016 International Conference on Industrial Engineering, Management Science and Application (ICIMSA)*, 1–4.

Uliyandari, M., & Lubis, E. E. (2020). Penerapan model pembelajaran inkuiri dengan media alat peraga (gunung berapi) pada mata pelajaran IPA SDN 013 Bengkulu Utara. *PENDIPA Journal of Science Education*, *4*(2), 74–78.

Utami, P. U., Yelianti, U., & Dwi Kartika, W. (2021). Pengembangan buku ilmiah populer keanekaragaman mangrove berbasis pembelajaran kontekstual pada materi keanekaragaman hayati di SMA. *Edu-Sains Volume*, *10*(2), 14–20.