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Fostering 21st-Century Problem-Solving: The Efficacy of the Deep Learning-Integrated INSPIRE Model in Science Education

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Abstract: Twenty-first-century learning, particularly in biology education, emphasizes the development of critical thinking and problem-solving skills as essential 4C competencies. However, current evidence indicates that Indonesian students' problem-solving abilities remain low, as reflected in the 2022 PISA results, which show that only 31% of students achieved basic creative thinking skills. This study aims to address this gap by examining the effectiveness of the INSPIRE (Identifying, Nurturing, Setting up, Planning, Investigating, Reasoning, Ending) learning model integrated with a deep learning approach defined here as a pedagogical framework emphasizing meaningful, mindful, and joyful learning on students' problem-solving skills in biology. This quasi-experimental study was conducted at SMA Negeri 1 Piyungan, Yogyakarta, during the odd semester of the 2024/2025 academic year and involved 72 tenth-grade students studying the environmental change material. Participants were purposively selected from two intact classes (n=36 each) based on equivalent characteristics, balanced prior academic performance, and schedule availability. The study employed a pretest-posttest non-equivalent control group design, with the experimental group receiving instruction through the INSPIRE model enriched with e-modules and guided inquiry activities. In contrast, the control group experienced conventional lecture-based teaching. Problem-solving abilities were measured using a validated six-item essay test covering four Polya indicators: understanding the problem, devising a plan, carrying out the plan, and looking back (r=0.368-0.579; á=0.923). Data analysis using an independent-samples t-test revealed statistically significant differences between groups ($t = -27.195$, $df = 70$, $p < 0.001$), with the experimental class achieving a mean posttest score of 92.01 (SD = 3.50) compared to the control class mean of 62.15 (SD = 5.57). Cohen's d effect size calculation yielded 0.98, indicating a large practical significance. The experimental group demonstrated a gain score of 58.24 points, compared with 28.82 in the control group. These findings provide empirical evidence that the deep learning-based INSPIRE model effectively enhances students' problem-solving skills in biology, offering a viable pedagogical alternative to conventional instruction methods.

Keywords: biology learning, deep learning, environmental change, INSPIRE model, problem solving.

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INTRODUCTION

Biology is one of the branches of Natural Sciences (IPA). Biology is a subject studied by students at the high school or Madrasah Aliyah level, which is considered difficult and unpleasant because it involves many theories that require memorization, as well as boring and unpleasant learning models (Ukhtikhumayroh & Rahmatsyah, 2020). Biology examines many aspects of nature and the environment that humans can observe and apply in everyday life. By studying biology, students can understand various phenomena and problems, reflect, analyze, and be able to solve problems or problem solving (Nursita et al., 2015). Thus, problem-solving is an important part of learning, especially in biology.

Problem-solving skills, defined as the ability to solve contextual problems using rational thinking, are among the skills needed in the 21st century (Wolf et al., 2023; Wongchantra et al., 2022). The National Research Council (2016) has also identified problem-solving skills as needed by society and the world of work in the 21st century, alongside several other skills. Due to the urgency of this skill, students, including high school students, are in dire need of improving it, as recommended by the government-implemented curriculum (Araiza-Alba et al., 2021; Rios et al., 2020).

Although the urgency of problem-solving skills is well-recognized, empirical evidence reveals persistent challenges in Indonesian students' achievement in this domain. The most recent PISA 2022 results demonstrate that only 31% of Indonesian students have achieved basic creative thinking skills (level 3), indicating their capacity is limited to generating ideas for simple to moderately complex problems. More concerning, merely 5% of students reached the advanced levels (5 or 6), suggesting a significant gap in students' ability to employ innovative and sophisticated problem-solving strategies (OECD, 2024). National assessment data from the 2023 Asesmen Nasional further corroborate this finding, showing that 68% of Indonesian high school students scored below the minimum competency threshold in scientific reasoning and problem-solving tasks (Safari & Khasanah, 2023).

At the classroom level, several recent studies have documented the prevalence of low problem-solving abilities among Indonesian biology students. Research by Elindra & Rahma (2019), involving 156 high school students across three districts in West Nusa Tenggara, revealed that 72% of participants demonstrated inadequate problem-solving skills, particularly in the stages of planning and implementing solutions. Similarly, studies conducted in Malang by Triani et al. (2023) and in West Java by Marsel & Fadilah (2025) reported comparable findings, with average problem-solving scores ranging from 42 to 58 out of 100, categorized as low to moderate. More recently, Angraini et al. (2025) conducted a comprehensive analysis of 245 high school students in Makassar and found that 65% struggled with translating biological concepts into practical problem-solving contexts. International comparative studies further indicate that Indonesian students consistently underperform relative to peers from neighboring ASEAN countries on biology problem-solving assessments (Knopfel et al., 2024; Lee & Tan, 2023).

The persistent low performance in problem-solving skills can be attributed to multiple interrelated factors operating at both systemic and instructional levels. At the instructional level, students are rarely exposed to authentic problem-solving experiences that require higher-order thinking, as classroom activities predominantly emphasize rote memorization and reproduction of factual knowledge rather than application and analysis (Ainy et al., 2024; Permana & Setiawan, 2023). This pedagogical approach fails to develop students' capacity to transfer learned concepts to novel situations, a critical component of effective problem-solving. Furthermore, the limited use of contextual and inquiry-based learning materials contributes to students' difficulty in connecting theoretical biological concepts with real-world problems they might encounter (Wijaya et al., 2023). The types of questions provided also do not train students to think critically when solving problems because they are neither concrete nor sufficiently complex (Elindra & Rahma, 2019). To improve problem-solving skills, teachers need to implement problemcentered learning models or approaches and accustom students to practicing with contextual questions related to real-life situations. Such practice will help students become more skilled at finding solutions and developing their learning strategies independently (Santoso et al., 2022). Recent meta-analyses suggest that student-centered pedagogical approaches, particularly those incorporating guided inquiry and reflection, can yield effect sizes ranging from 0.65 to 1.2 on problem-solving outcomes, significantly outperforming traditional lecture-based instruction (Freeman et al., 2014; Hattie, 2008).

In response to these pedagogical challenges, educational researchers and practitioners have increasingly advocated for learning approaches that promote deeper engagement with content. One such approach is deep learning, a term in educational contexts that refers to a pedagogical framework fundamentally distinct from the artificial intelligence concept of the same name. In education, deep learning is defined as an approach that emphasizes meaningful, mindful, and joyful learning experiences (Jiang, 2022; Levin, 2024). This approach prioritizes students' conscious and reflective engagement with material, encourages emotional investment in the learning process, and facilitates the construction of well-integrated knowledge structures rather than superficial memorization (Errabo et al., 2024). The Indonesian Ministry of Education has formally adopted this deep learning framework as a central policy since 2024, recognizing its potential to address persistent challenges in developing students' higher-order thinking skills (Kemdikbudristek, 2024).

To contextualize the specific challenges at the research site, a preliminary study was conducted in August 2024 at SMA Negeri 1 Piyungan through semi-structured interviews with three biology teachers and classroom observations of six biology lessons across different grade levels. The interviews revealed that instruction remained predominantly teacher-centered and content-focused, with approximately 75% of class time devoted to teacher exposition and note-taking. Teachers acknowledged that their instructional approach prioritized content coverage and memorization to prepare students for standardized assessments, with limited opportunities for inquiry-based or problem-solving activities. This pedagogical orientation was confirmed through classroom observations, which documented minimal student participation in generating questions, designing investigations, or engaging in collaborative problem-solving.

In addition, based on observations of biology lessons in the classroom, it was found that teachers used the lecture method. In this lecture method, teachers usually explain the material and give questions for students to complete. Based on these observations, it was found that students lacked an understanding of the material in a contextual and meaningful way. Another problem described above is that students are not active enough in biology lessons because teachers do not actively involve them in the learning process. As a result, students are not accustomed to solving problems. In addressing the documented deficiencies in problem-solving skills and the identified limitations of conventional instruction, there exists a critical need for an evidence-based pedagogical intervention specifically designed to operationalize the principles of deep learning. While the Indonesian government (Kemdikbudristek, 2024) has recommended several established learning models as potentially suitable for implementing deep learning, including Guided Inquiry-Based Learning, Problem-Based Learning, and Project-Based Learning, these existing models present certain limitations when examined through the lens of deep learning principles. Specifically, conventional inquiry models tend to emphasize the cognitive and procedural dimensions of learning while paying insufficient attention to the reflective, affective, and metacognitive components central to deep learning (Cheng & Tsai, 2019; Prince & Felder, 2021).

However, the learning models that have been known and implemented so far do not always create a learning atmosphere and process that are mindful, meaningful, and joyful, through intellectual, ethical, aesthetic, and physical (kinesthetic) exercise in a holistic and integrated manner. As an alternative have developed a learning model specifically designed to create such a learning atmosphere, called INSPIRE. INSPIRE is also designed to encourage students to engage in intellectual, ethical, aesthetic, and physical activities.

The INSPIRE learning model is a further development of guided inquiry-based learning, enriched with e-modules and inspired by the Indonesian government's definition of deep learning approaches (Kemdikdasmen, 2025). INSPIRE was developed based on aspects of the deep learning approach. The INSPIRE learning model has characteristics described by Joyice et al. (2015) as follows. The INSPIRE learning model is based on three learning concepts/theories, namely constructivism, social cognition, and humanism. The INSPIRE learning model has the following syntax: (1) Identifying basic concepts, (2) Nurturing Problems, (3) Setting Up Hypotheses, (4) Planning Investigations, (5) Investigating Empirical Evidence, (6) Reasoning and Concluding, and (7) Ending with Reflection. This model builds a social system in the form of groups of students who work effectively from the beginning to the end of the syntax, with teachers serving as guides in the learning process.

The deep learning approach, which, according to Kushwaha (2025) and Errabo et al. (2024), encompasses the concepts of meaningful, mindful, and joyful learning, has been gaining traction as a central government policy since 2024. This learning approach still requires a relevant learning model to be implemented in schools in Indonesia. Therefore, implementing the developed deep-learning-based INSPIRE learning model is urgently needed to enhance learning and potentially improve students' problem-solving abilities, especially in biology.

Theoretically, the deep learning approach emphasizes the creation of a meaningful, mindful, and joyful learning process, in which students not only understand concepts superficially but also engage consciously, reflectively, and emotionally positively in learning (Jiang, 2022; Kushwaha, 2025). These principles are systematically internalized in each phase of the INSPIRE model syntax. In the Identifying Basic Concepts and Nurturing Problems stages, students are guided to relate their prior knowledge to contextual problems that are relevant to real life. This activity theoretically facilitates meaningful learning because learning is built through the process of activating cognitive schemas and contextual conceptualization, rather than simply receiving information passively. Furthermore, during the Setting Up Hypotheses and Planning Investigations stages, students engage in a conscious, focused problem-solving process. This stage requires students to monitor their own thinking processes, consider various alternative solutions, and make decisions based on logical reasoning. Thus, this phase facilitates mindful learning, which emphasizes metacognitive awareness and control of students' thinking processes (Prince & Felder, 2021). The Investigating Empirical Evidence and Reasoning and Concluding stages encourage students to actively engage in data exploration, hypothesis testing, and evidence-based drawing of conclusions. This process not only deepens conceptual understanding but also trains higher-order thinking skills, particularly the ability to solve problems systematically and evidence-based. Meanwhile, the Ending with Reflection stage plays an important role in fostering joyful learning, as students are given space to reflect on their learning experiences, assess the effectiveness of the strategies used, and express their understanding and feelings throughout the learning process. This reflection strengthens students' positive emotional engagement and encourages intrinsic motivation in learning (Spector, 2014).

Despite the Indonesian government's endorsement of inquiry-based learning models as vehicles for implementing deep learning, empirical evidence suggests significant limitations in their capacity to simultaneously cultivate mindful, meaningful, and joyful learning experiences. A systematic review of 47 studies on inquiry-based learning in Indonesian secondary science education (Rahayu & Kita, 2023) revealed that conventional Guided Inquiry approaches typically emphasize cognitive and procedural dimensions, such as hypothesis generation and experimental design, while providing minimal scaffolding for metacognitive reflection, emotional engagement, or kinesthetic involvement. Consequently, while these models may enhance conceptual understanding, they often fail to develop the holistic competencies encompassed by the deep learning framework (Cheng & Tsai, 2019; Hmelo-Silver et al., 2007).

Unlike existing inquiry models, the INSPIRE model offers fundamental innovation, not merely in terms of syntactic terminology, but in the explicit integration of deep learning principles, the use of e-modules to enhance the learning experience, and the design of activities that consciously involve students' intellectual, social, ethical, aesthetic, and physical dimensions. INSPIRE not only guides students in discovering concepts but also places reflection, metacognitive awareness, and emotional engagement at the core of the learning process. Thus, INSPIRE is positioned not only as an alternative inquiry model but also as an innovative solution designed to address the limitations of similar learning models in facilitating deep learning and comprehensively improving students' problem-solving abilities.

METHOD

Participants

The population of this study comprised all 10th-grade students at Piyungan 1 Public High School in the 2024/2025 academic year. The research population consisted of all 10th-grade science classes at Piyungan 1 Public High School, totaling 5 classes and 180 students. The sample selection employed a two-stage purposive sampling procedure to ensure comparability between experimental and control groups while accommodating the practical constraints of intact classroom groups. In the first stage, three of the five science classes (X IPA 1, X IPA 3, and X IPA 5) were identified as potentially suitable based on preliminary analysis of their prior academic performance. Specifically, classes were included if their mean grade point average from the previous semester (Semester 2, academic year 2023/2024) fell within one standard deviation of the school-wide mean (M = 78.5, SD = 4.2), ensuring relatively homogeneous baseline academic ability across groups. This criterion excluded X IPA 2 (M = 71.3, below threshold) and X IPA 4 (M = 86.7, above threshold) from consideration.

In the second stage, from the three eligible classes, two were selected for inclusion in the study: X IPA 1 (n = 36) and X IPA 5 (n = 36). The selection was based on three practical considerations: (1) schedule compatibility both classes had biology instruction scheduled during time blocks that allowed consistent implementation by the same teacher; (2) teacher availability the regular biology teacher for both classes agreed to participate and implement the assigned instructional approaches; and (3) class composition balance neither class included students with identified special educational needs that might require substantial instructional modifications. Random assignment of these two intact classes to experimental and control conditions was conducted by coin toss, with X IPA 5 assigned to the experimental condition (INSPIRE model) and X IPA 1 assigned to the control condition (conventional instruction).

To verify baseline equivalence between groups, an independent-samples t-test was conducted on students' prior-semester biology grades. Results indicated no statistically significant difference between X IPA 5 ($M = 77.8$, $SD = 5.1$) and X IPA 1 ($M = 78.2$, $SD = 4.9$), $t(70) = 0.34$, $p = .73$, confirming group comparability. Additionally, a pretest of problem-solving skills administered one week before intervention onset yielded similar scores for the experimental group ($M = 33.77$, $SD = 3.20$) and control group ($M = 33.33$, $SD = 5.10$), $t(70) = 0.42$, $p = .68$, further supporting baseline equivalence.

Research Design

This quasi-experimental study was conducted from September 22 to October 8, 2025, at SMA Negeri 1 Piyungan, Bantul Regency, Yogyakarta. This study comprises two variables: the independent and dependent variables. The independent variable (X) in this study is the Deep Learning-Based INSPIRE Learning Model, which affects the dependent variable (Y). Meanwhile, the dependent variable (Y) is the variable influenced by the independent variable (X) in this study, namely, problem-solving skills. The research design used in this study is a pretest-posttest control group design. In this design, the experimental and control groups are selected randomly. The experimental and control groups are administered a pretest, then receive treatment, and finally a posttest (Sugiyono, 2019). This research design uses a non-equivalent control group design, with one experimental class receiving the INSPIRE learning model treatment and one control class not receiving the treatment, implementing learning as usual.

This study consists of three stages, namely:

Planning Stage

This stage includes: preliminary studies of existing problems and literature studies on deep learning-based learning. A curriculum review is conducted to determine the teaching modules/ lesson plans (RPP). The purpose of this curriculum review is to ensure that the learning model implemented is in line with the objectives to be achieved, the creation of student worksheets (LKPD), the creation of e-modules, the creation of problem-solving ability instruments, the determination of the classes to be used as research sites, and the preparation of a learning activity schedule.

Implementation Stage

The implementation stage includes conducting a pretest, implementing learning activities using the INSPIRE deep learning-based model, and administering a posttest. In implementing the learning activities, the control class used a conventional model, while the experimental class used the INSPIRE learning model based on deep learning. The INSPIRE model consists of seven sequential phases implemented across four 90-minute instructional sessions (one session per week over four weeks). Each phase explicitly integrates one or more deep learning principles: meaningful learning (connecting new knowledge to prior understanding and real-world contexts), mindful learning (conscious, focused engagement with metacognitive awareness), and joyful learning (positive emotional engagement and intrinsic motivation). The operational details of each phase are as follows: Phase 1: Identifying Basic Concepts (15 minutes). Students accessed e-modules via their mobile devices or school computers one week before each class session. The e-modules, developed specifically for this study and validated by two expert lecturers (validation score: 3.86/ 4.00), presented core biological concepts related to environmental change through multimedia resources including text, diagrams, animations, and short videos. Each module concluded with 5-7 multiple-choice formative assessment items and reflective prompts asking students to connect concepts to their daily experiences. This phase facilitated meaningful learning by activating prior knowledge and establishing conceptual foundations before in-class inquiry activities.

Nurturing Problems from Phenomena (20 minutes). Teachers presented authentic environmental problems through contextual discourse or video cases (e.g., waste accumulation near Piyungan landfill, river pollution in Yogyakarta). Students, organized into heterogeneous groups of 4-5 members, discussed the phenomena and generated questions. Teachers facilitated questioning through prompts such as "What biological concepts explain this phenomenon?" and "What factors might contribute to this problem?" This phase promoted meaningful learning by situating abstract concepts in relevant real-world contexts and encouraged mindful learning through deliberate attention to causal relationships. Phase 3: Setting Up Hypotheses (15 minutes). Building on their questions, student groups formulated testable hypotheses regarding the environmental problems. Teachers provided scaffolding through hypothesis templates and guiding questions. Groups recorded their hypotheses on the Student Worksheet (LKPD), which were validated by experts (validation score: 3.96/4.00). This phase cultivated mindful learning by requiring conscious reasoning about cause-and-effect relationships and the identification of variables.

Phase 4: Planning Investigations (20 minutes). Groups designed investigation procedures to test their hypotheses, specifying required materials, data collection methods, timeline, and location. Teachers guided the planning through questions that addressed feasibility, safety, and scientific rigor. Groups documented their investigation plans in the LKPD. This phase emphasized mindful learning through metacognitive planning and decision-making about methodological choices. Phase 5: Investigating Empirical Evidence (45 minutes, conducted outside regular class time). Groups conducted field investigations in their neighborhoods or school surroundings to gather empirical evidence. For example, groups investigating waste problems surveyed community waste management practices, photographed disposal sites, or interviewed residents. Teachers monitored progress through group check-ins but allowed substantial student autonomy. This phase integrated meaningful learning (applying concepts in authentic contexts) and joyful learning (active, hands-on engagement that fosters intrinsic motivation).

Phase 6: Reasoning and Concluding (30 minutes). Groups analyzed their investigation data, related findings to their hypotheses, and drew evidence-based conclusions. Each group created a solution proposal addressing the identified environmental problem and, when feasible, developed a tangible product (e.g., a composting bin, an informational poster, or a waste-segregation guide). Groups presented their findings (10 minutes per group) using multimedia formats. Peer groups provided feedback through structured protocols. This phase reinforced meaningful learning through knowledge application and mindful learning through analytical reasoning.

Phase 7: Ending with Reflection (15 minutes). Teachers facilitated individual and group reflection through structured prompts: "What did you learn about the environmental problem?" "What strategies worked well in your investigation?" "What would you do differently next time?" "How do you feel about your learning experience?" Students documented reflections in learning journals. This phase explicitly cultivated mindful learning (metacognitive awareness of learning processes) and joyful learning (opportunity to acknowledge accomplishments and positive experiences).

Final Stage

The final stage includes: processing data and comparing the results of data analysis on problem-solving ability tests before and after the treatment to determine whether the INSPIRE learning model, based on deep learning, affects problem-solving ability; and drawing conclusions based on the processed data.

Instruments

The research instrument used in this study was a problem-solving ability test administered to students before the treatment (pre-test) and after the treatment (post-test). This research test instrument consisted of an essay containing six questions about environmental change. The instrument's questions covered four indicators of problem-solving ability, adapted from Polya & Conway (2004).

Problem-Solving Skills Assessment Instrument

Students' problem-solving skills were assessed using a researcher-developed essay test comprising six items aligned with (Polya & Conway, 2004) four-stage problem-solving framework: (1) understanding the problem, (2) devising a plan, (3) carrying out the plan, and (4) looking back. The instrument was designed specifically for the environmental change topic in the 10th-grade biology curriculum. Question 1 assessed understanding the problem; Questions 2-3 assessed devising a plan; Questions 4-5 assessed carrying out the plan; and Question 6 assessed looking back/reflection (see Table 1 for complete item specifications).

The problem-solving ability test used in this study was an essay test. The questions in the problem-solving ability test instrument were based on four problem-solving indicators: understanding the problem, devising a plan, carrying out the plan, and looking back (Polya & Conway, 2004). Understanding the problem is necessary to prevent students from making mistakes from the outset due to misinterpreting information, problems, or material concepts, which is the first step in problem-solving. Devising a plan emphasizes students' steps in planning to solve problems and identifying relationships between variables, which will later align with experimental activities and conceptual discussions in biology. Carrying out the plan provides an opportunity for students to apply the selected strategies and begin an implementation process that will produce initial answers to the problem. Meanwhile, looking back trains students to develop reflective skills, namely, reviewing the steps taken (Savary, 2006).

Therefore, by focusing on these four indicators, the instrument becomes more valid, measurable, and aligned with the research objective of assessing the operational improvement in students' problem-solving abilities through biology learning activities. Each essay question has four assessment criteria. If students answer correctly with detailed explanations, they will get a score of 4 (four); if they answer correctly but lack detail, they receive a score of 3 (three); if they answer correctly but provide no explanation, they receive a score of 2 (two); if they answer incorrectly but provide a detailed explanation, they receive a score of 1 (one); if they do not answer or their answer is irrelevant, they receive a score of 0 (zero).

The four Polya indicators were selected because they comprehensively capture the cognitive processes involved in biological problem-solving: Understanding the problem is necessary to prevent students from making mistakes from the outset due to misinterpreting information, problems, or material concepts, which is the first step in problem-solving. Devising a plan emphasizes students' steps in planning to solve problems and identifying relationships between variables, which will later align with experimental activities and conceptual discussions in biology. Carrying out the plan provides an opportunity for students to apply the selected strategies and begin an implementation process that will produce initial answers to the problem. Meanwhile, looking back trains students to develop reflective skills, namely, reviewing the steps taken (Savary, 2006).

Table 1. Problem-solving ability instrument grid

Problem Solving	**Sub Indikator *Problem Solving***	**Question**	**No.**
(understanding the problem)	Understanding the causes and effects of problems	Consider the following discourse: "Many people litter on roads, rivers, and even tourist attractions. They think that their trash will be cleaned up by local sanitation authorities, so they feel free to litter. In addition, they are unaware of the future consequences of littering. Based on data obtained from the Central Statistics Agency, Indonesia's national waste production reaches 64 million tons per year. This is a warning to the government and environmentalists, including teachers and students, to address the problem immediately so it does not cause major problems in the future. The government is expected to respond immediately and design programs that can overcome this problem." Source: ceritabaikindonesia.id, January 7, 2025 1. Based on the discussion above, why can littering become a problem and impact the environment and community life? List at least 4 impacts!	1
(devising a plan)	Developing solution plans based on problems	2. Based on the above discussion, provide one suggestion to address this issue and give logical reasons why this suggestion is considered the best way to prevent similar problems in the future.	2,3
	Developing a collaborative plan	3. Imagine you are a member of the Yogyakarta environmental awareness team. What action plan would you implement with residents to reduce waste problems? Explain!	
(carrying out the plan)	Implementing the plan	4. A school near the Piyungan landfill prohibits its students from using disposable plastic bottles to reduce waste, especially in the school environment. Do you think this policy is appropriate? Why?	4,5
	Apply solutions immediately	5. What are some simple actions you can take at home to help reduce waste problems? Explain how.	
(looking back)	Reflection on the effectiveness of solutions	Consider the following statement: “The Piyungan TPST in the Bantul area has been closed because it is full. As a result, a lot of garbage has piled up around residential areas and schools.” The DIY government said that this policy had been agreed upon with the regents and mayors. Therefore, each regency and city	6

will manage its own waste starting in April 2024. He also urged each region to prepare and operationalize the construction of waste processing facilities. "The solution is that waste management will no longer be handled at the landfill, but directly by the community using processing methods and facilities in accordance with the policies of each district and city," Source: Tribunjogja.com, April 5, 2024

2. In your opinion, is the government's policy/solution sufficient to address the waste problem? Can the government's policy/solution be improved? Write down your reasons!

Scoring Rubric

Each essay item was scored using a 5-point analytic rubric (0-4 points) based on response completeness and quality of reasoning. The rubric criteria were as follows: 4 points: Response is completely correct with a detailed, scientifically accurate explanation demonstrating deep conceptual understanding and clear logical reasoning. 3 points: Response is correct, but explanation lacks some detail or contains minor inaccuracies that do not fundamentally undermine the answer. 2 points: Response is partially correct, but explanation is minimal, superficial, or contains significant conceptual gaps. 1 point: Response shows some relevant attempt, but the conclusion is incorrect despite providing some explanation or reasoning. 0 points: No response provided, response is completely irrelevant, or response shows no understanding of the problem.

Data Analysis

Data analysis in this study was divided into two parts: analysis of the instruments used and analysis of the data obtained (descriptive and inferential). The research instruments, which used problem-solving ability tests, were first assessed for validity and reliability. Based on the validity test results involving two experts, consisting of two expert lecturers. This aims to determine the validity of the content set using an expert assessment sheet. Instruments that two experts have assessed will then be revised with the help of a supervisor if any questions are inappropriate. The revised questions were then tested on 36 students who had studied material on environmental change. Based on the validity test results involving two experts, all learning tools and research instruments were declared valid because the interpretation of the expert assessment scores from the Likert scale for the teaching module/ lesson plan was 3.85, the expert validator for the e-module was 3.86, and expert validators for the LKPD of 3.96 with an average validity score of 3.89 and expert assessments of the problem-solving ability instrument with an average validity score of 3.75. Thus, it can be concluded that the research tools and instruments developed meet the validity criteria and are suitable for use to proceed to the research trial stage.

Furthermore, the validity of the problem-solving ability test items was calculated using product-moment correlations, with values ranging from 0.368 to 0.579, indicating that all questions were considered valid. A question is considered valid if the table r value is greater than the calculated r (0.361). After the test items' validity was established, a reliability test was conducted. The reliability of the problem-solving ability test instrument was assessed using Cronbach's alpha, yielding a value of 0.923, exceeding the recommended threshold of 0.70 and indicating good reliability. The results of the analysis of the problem-solving ability test instrument indicate that it is valid and meets reliability requirements, making it suitable for assessing problem-solving abilities. Before proceeding to the next stage, the results of the problem-solving ability test instrument (pretest and posttest) will be grouped into five groups to determine the score distribution:

Table 2. Score categorization

Interval Skor	Criteria
91.67 < X ≤ 100	Very High
83.34 < X ≤ 91.67	High
75 < X ≤ 83.34	Medium
66.67 < X ≤ 75	Low
0 < X ≤ 66.67	Very Low

After all instruments met the instrument-testing requirements, they were administered to the research sample to obtain raw data for further processing. The data were then analyzed using descriptive and inferential statistics in SPSS version 25. Before conducting the independent-samples t-test, this study conducted a two-stage preliminary analysis: a normality test and a homogeneity-of-variances test. The normality test aims to determine whether the data being studied comes from a normally distributed population. The normality test was performed using the Lilliefors test. Meanwhile, the homogeneity test was performed to determine whether the two samples being compared had the same variance, indicating homogeneity of variance. After meeting the normality and homogeneity requirements, a test of the difference between pretest and posttest scores was conducted using the Independent Sample T-Test. If the data met the requirements for normality and homogeneity, a t-test was performed. If the data did not meet the requirements of normality and homogeneity, a nonparametric test was conducted using the Mann-Whitney test. Furthermore, after determining whether the deep learning-based INSPIRE learning model had a significant effect on students' problem-solving abilities, the magnitude of the effect was assessed using Cohen's d. Cohen's d was used to determine the practical significance of the difference between the experimental and control groups (Lakens, 2013).

The interpretation of effect sizes followed Cohen's (2013) criteria: d < 0.20 indicates a very small effect, 0.20 d" d < 0.50 indicates a small effect, 0.50 d" d < 0.80 indicates a medium effect, and d e" 0.80 indicates a large effect. The classification of Cohen's d values is presented in Table 3.

Table 3. Interpretation of cohen's d effect size

Effect Size Category	Cohen's d Value
Very Small	d < 0.20
Small	0.20 ≤ d < 0.50
Medium	0.50 ≤ d < 0.80
Large	d ≥ 0.80

RESULT AND DISCUSSION

Putting the Deep Learning-based INSPIRE Learning Model into action

The deep learning-based INSPIRE model was successfully executed during four weeks (September 22–October 8, 2024), comprising one 90-minute session each week, culminating in four instructive sessions. Two independent observers (inter-rater reliability, ê = 0.87) used classroom observation methods to assess implementation fidelity. They looked for and rated the existence and quality of each INSPIRE phase during teaching. The results showed that all seven phases were used in all the courses watched. The average quality rating for the implementation was 3.6 out of 4.0, which means that the model's design specifications were followed very closely.

As planned, each INSPIRE phase included one or more deep learning concepts. During the Identifying Basic Concepts phase, students worked on e-modules outside of class. Access logs showed that 94% of the experimental students (34 out of 36) finished the pre-class module assignments. Teachers said that this pre-learning helped students learn more meaningfully by providing a conceptual basis before they conducted any in-class research. During the Nurturing Problems from Phenomena phase, students showed strong interest when they were given environmental problems relevant to their area, including garbage concerns near the Piyungan dump. Observation notes indicated that 89% of students actively engaged in formulating questions, with groups generating an average of 4.2 questions per scenario (range: 2–7 questions), demonstrating effective contextualizat of learning.

During the Setting Up Hypotheses and Planning Investigations phases, students participated in collaborative reasoning concerning causal linkages and methodological choices. An examination of the Student Worksheets (LKPD) indicated that all nine groups in the experimental class effectively developed testable hypotheses, albeit with varying quality. An expert evaluation using a four-point rubric yielded a mean quality score of 2.8 (SD = 0.6) for the hypotheses. This means that the hypotheses were generally good but might be improved. The ideas for the investigations showed both originality and practicality. For example, six groups suggested surveys, eight suggested photographic evidence, three suggested trash audits, and five suggested interviews. These phases helped people learn mindfully by prompting them to plan and make decisions with metacognition.

The Investigating Empirical Evidence portion, which took place outside of regular class hours, was quite interesting. All groups finished their field investigations, and photo documentation and investigation diaries showed that they had indeed collected data. Post-intervention surveys revealed that 83% of experimental students reported enjoying the hands-on investigations (rating e" 4 on a five-point scale), and 78% felt that the activities facilitated a deeper understanding of environmental change concepts compared to traditional textbook learning. During this stage, teachers saw a lot of energy, initiative, and tenacity, which showed that the principles of meaningful learning and happy learning were working well together.

H1: Effect of the INSPIRE Model on Overall Problem-Solving Skills

Table 4 presents descriptive statistics for students' problem-solving scores in the experimental and control groups before and after the test. Both groups had similar baseline performance. The experimental group had a mean pretest score of 33.77 (SD = 3.20), and the control group had a mean of 33.33 (SD = 5.10). This shows that the two groups were the same at the start.

Table 4. Shows the average scores and standard deviations for the pretest and posttest in both the experimental and control courses

Groups	***Pretest***		***Posttest***	
	x	**s**	**x**	**s**
Control	33.33	5.10	62.15	5.57
Experiment	33.77	3.20	92.01	3.50

After the intervention, both groups improved, but the degree of improvement differed markedly. The control group's average posttest score increased to 62.15 (SD = 5.57), a gain of 28.82 points. The experimental group, on the other hand, had a mean posttest score of 92.01 (SD = 3.50), representing a gain of 58.24 points. The experimental group's gain was approximately twice that of the control group, indicating that the instruction was far more effective in practice.

We grouped the pretest and posttest scores into five categories to examine the score distributions: Very Low, Low, Medium, High, and Very High. Based on the descriptive analysis of students' problem-solving abilities in the pretest and posttest of the experimental class, data showed differences in achievement across four indicators: understanding the problem, devising a plan, carrying out the plan, and looking back. The following is the data from the pretest and posttest in the experimental class.

The pre-test results show the percentage distribution of the experimental class students' abilities across each problem-solving indicator,

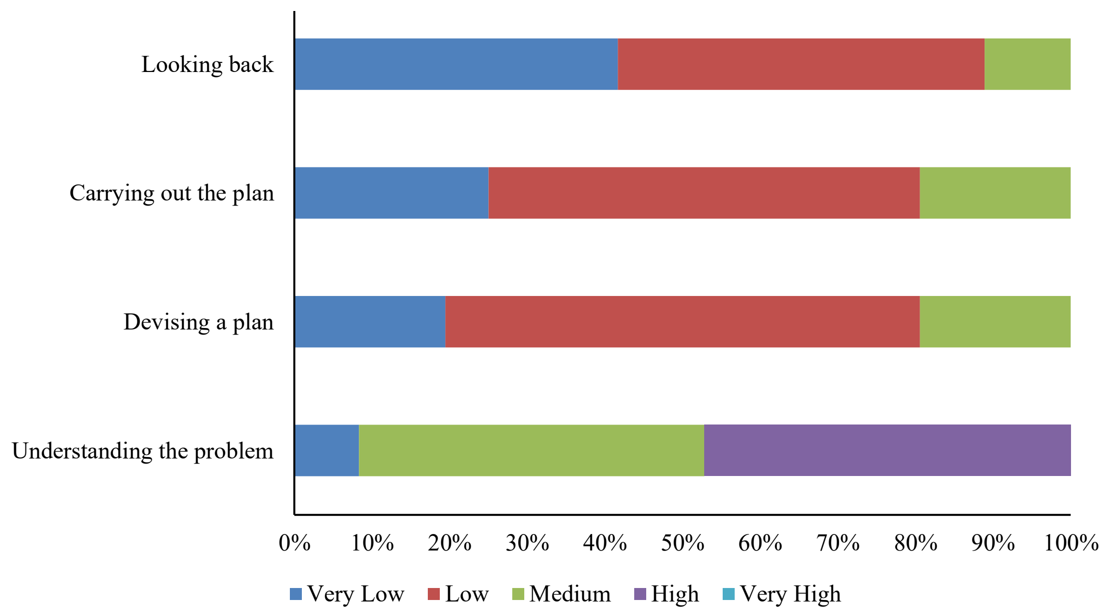

Figure 1. 100% stacked bar chart pre-test results of experimental class students per category for each indicator

grouped into five levels: very low, low, medium, high, and very high. On the "understanding the problem" indicator, the percentage scores were very low at 8.3%, medium at 44.5%, and high at 47.2%. The "devising a plan" indicator showed very low (19.5%), low (61.1%), and medium (19.4%). The "carrying out the plan" indicator showed very low (25%), low (55.6%), and medium (19.4%). Meanwhile, the "looking back" indicator showed very low (41.7%), low (47.2%), and medium (11.1%). In general, the pre-test results showed that most students in the experimental class remained in the very low, low, and medium categories.

The post-test results also show the percentage distribution of the experimental class students' abilities for each problem-solving indicator, grouped into five levels: very low, low, medium, high, and very high. On the "understanding the problem" indicator, the percentage scores were very low at 8.3%, medium at 44.5%, and high at 47.2%. The "devising a plan" indicator had a medium score of 5.6%, a high of 61.1%, and a very high of

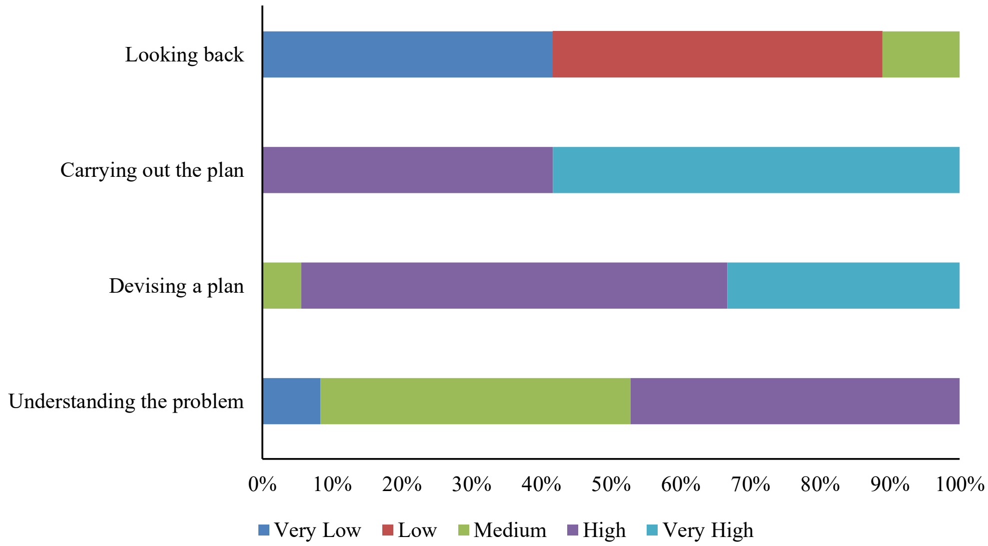

Figure 2. 100% stacked bar chart post-test results of experimental class students per category for each indicator

33.3%. The "carrying out the plan" indicator showed a high percentage of 41.7% and a very high percentage of 58.3%. Meanwhile, the "looking back" indicator showed very low (41.7%), low (47.2%), and medium (11.1%). Overall, the post-test results showed a shift in the distribution of categories from low to high and very high, particularly for the indicators of devising and carrying out a plan. This improvement was obtained after the deep learning-based learning model was implemented in the classroom.

Table 4. Hypothesis test results using independent sample T-Test

		Levene's Test		t-test for Equality of Means						
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std.Error Difference**	**95% Confidence Interval of The Difference**	
									Lower	**Upper**
Posttest Score	Equal Variances Assumed	1.733	.192	-27.195	70	.000	-29.86056	1.09800	-32.05044	-27.67067

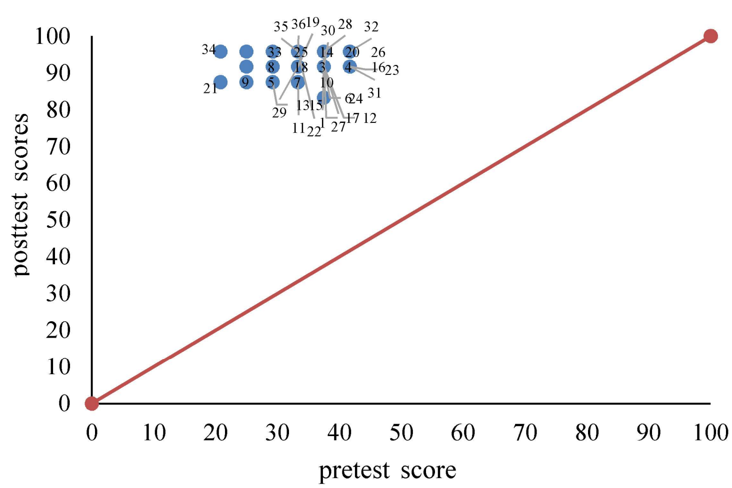

Figure 3. Distribution of pretest and posttest scores for each student

H2: The INSPIRE Model Significantly Improves Students' Ability to Understand Problems

To evaluate the varying impacts on problem-solving components, student performance was assessed for each of Polya's four indicators. We calculated the mean scores and rescaled them to 0 to 100. Table 5 shows the means, gain scores, and normalized gains (N-gain) for each indicator before and after the test.

Table 5. Scores for the pretest, posttest, and N-gain by problem-solving indicator

Indicator	Group	Pretest M (SD)	Posttest M (SD)	Gain	N-Gain
Understanding the Problem (Item 1)	Experimental	32.1 (6.2)	93.8 (4.1)	61.7	0.91
	Control	31.5 (7.1)	68.2 (8.3)	36.7	0.54
Devising a Plan (Items 2-3)	Experimental	30.8 (5.8)	89.5 (5.2)	58.7	0.85
	Control	30.2 (6.5)	61.3 (7.9)	31.1	0.45
Carrying Out the Plan (Items 4-5)	Experimental	35.2 (4.9)	91.8 (4.3)	56.6	0.87
	Control	34.8 (5.7)	59.7 (6.8)	24.9	0.38
Looking Back (Item 6)	Experimental	36.5 (7.3)	93.2 (5.6)	56.7	0.89
	Control	36.1 (8.2)	60.5 (9.1)	24.4	0.38

Note. N-gain = (Posttest - Pretest) / (100 - Pretest). N-gain interpretation: < 0.3 = low; 0.3-0.7 = medium; > 0.7 = high.

The experimental group had a high N-gain (0.91) for the "understanding the problem" indicator, while the control group had a medium N-gain (0.54). This shows that students taught using the INSPIRE model made much more progress.

The exceptionally high N-gain observed for the "understanding the problem" indicator in the experimental group underscores the INSPIRE model's effectiveness in facilitating students' initial comprehension of the problem. This improvement is closely related to the Identifying Basic Concepts and Nurturing Problems phases, during which students engaged with e-modules and contextual phenomena prior to in-class inquiry. These activities activated students' prior knowledge and supported conceptual clarity, thereby reducing misconceptions and cognitive overload.

Within Polya's problem-solving framework, understanding the problem is a critical foundational stage that determines success in subsequent steps. Failure at this stage often leads to ineffective solution strategies. The INSPIRE model addresses this challenge by scaffolding conceptual understanding before students proceed to planning and investigation, thus fostering meaningful learning through deliberate conceptual engagement (Polya & Conway, 2004; Prince & Felder, 2021).

H3: The INSPIRE Model Significantly Improves Students' Ability to Devise Solution Plans

The experimental group had a high N-gain of 0.85 for the "devising a plan" indication, while the control group had a medium N-gain of 0.45. This 0.40-point difference is the biggest disparity between all the metrics. It shows that the INSPIRE model was particularly effective at helping students learn to plan.

The largest disparity between the experimental and control groups emerged in the "devising a plan" indicator, indicating that the INSPIRE model is particularly effective in enhancing students' planning abilities. Devising a plan requires learners to integrate conceptual understanding with causal reasoning and strategic decision-making. The Setting Up Hypotheses and Planning Investigations phases explicitly trained students to formulate testable hypotheses and design systematic investigation procedures and activities, which are rarely emphasized in conventional instruction.

From a theoretical perspective, this phase embodies mindful learning, as students are required to consciously monitor their thinking processes, evaluate alternative strategies, and make reasoned decisions. Prior research has identified metacognitive planning as a key determinant of successful problem-solving, yet it is often underdeveloped in traditional inquiry-based learning environments (Prince & Felder, 2021). The present findings suggest that the INSPIRE model effectively addresses this gap.

H4: The INSPIRE Model Significantly Improves Students' Ability to Carry Out Solution Plans

The "carrying out the plan" indicator showed that the experimental group had a high N-gain (0.87) while the control group had a low N-gain (0.38). This finding shows that the INSPIRE model was particularly good at helping students learn how to use problem-solving strategies.

The high N-gain observed in the "carrying out the plan" indicator indicates that students in the experimental group effectively implemented their chosen strategies. Through field investigations and hands-on data collection activities, students applied biological concepts in authentic contexts, thereby strengthening procedural knowledge and problem-solving fluency. This experiential learning process aligns with the principles of meaningful learning, which emphasize the application of knowledge rather than rote memorization.

In contrast, the lower gains observed in the control group suggest that conventional lecture-based instruction provides limited opportunities for students to practice implementing problem-solving strategies. This finding supports previous studies indicating that active learning environments yield superior outcomes in science education compared to passive instructional approaches (Freeman et al., 2014; Hattie, 2008).

H5: The INSPIRE Model Significantly Enhances Students' Reflective Problem-Solving Capabilities

The experimental group had a high N-gain of 0.89 for the "looking back" indicator, while the control group had a low N-gain of 0.38. This large difference shows that the INSPIRE model had a big effect on how well students could think about and solve problems.

The substantial improvement in the "looking back" indicator underscores the importance of reflection in the INSPIRE model. The Ending with Reflection phase provided structured opportunities for students to evaluate the effectiveness of their strategies, recognize errors, and internalize successful approaches. Reflection is a critical yet often neglected component of problem-solving, as it promotes metacognitive awareness and supports long-term learning retention (Spector, 2014).

This phase also facilitated joyful learning by allowing students to acknowledge their achievements and express positive emotional engagement with the learning process. Positive emotional experiences have been shown to enhance intrinsic motivation and deepen cognitive engagement, thereby reinforcing problem-solving competence (Spector, 2014).

■ CONCLUSION

This study examined the effectiveness of the deep learning-based INSPIRE model on students' problem-solving skills in biology education. The findings provide empirical evidence that students receiving instruction through the INSPIRE model demonstrated significantly higher problem-solving abilities (M=92.01, SD=3.50) compared to those taught through conventional methods (M=62.15, SD=5.57), with a large effect size (Cohen's d=0.98). This substantial difference confirms that integrating deep learning principles (meaningful, mindful, and joyful learning) into a structured inquiry framework effectively enhances students' capacity to solve biological problems.

Theoretical Contribution: This research advances understanding of how pedagogical models can operationalize deep learning principles in science education. Unlike conventional inquiry models that primarily emphasize cognitive dimensions, the INSPIRE model demonstrates that the systematic integration of metacognitive reflection (mindful learning), contextual relevance (meaningful learning), and affective engagement (joyful learning) across all instructional phases yields superior problem-solving outcomes. The particularly strong improvements in "devising a plan" (N-gain=0.85) and "carrying out the plan" (N-gain=0.87) indicate that authentic investigation experiences, combined with explicit scaffolding, are critical mechanisms for developing higher-order problem-solving competencies.

Practical Implications: For biology educators, this study offers a viable alternative to lecture-based instruction that aligns with Indonesia's 2024 deep learning policy framework. The model's effectiveness across all student ability levels, particularly for initially lower-performing students, suggests its potential to reduce achievement gaps. Schools can adopt the INSPIRE model with appropriate professional development support, utilizing the e-modules and student worksheets validated in this study.

Limitations and Future Directions: The single-school setting and four-week intervention period limit generalizability. Future research should examine the implementation of INSPIRE across diverse school contexts, investigate long-term retention of problem-solving skills, and explore the model's effectiveness across different biology topics and grade levels. Additionally, research incorporating qualitative data on students' metacognitive development and emotional engagement would deepen understanding of the mechanisms through which deep learning principles enhance problem-solving abilities.

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DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

During the writing of this manuscript, the author(s) utilized generative AI tools to assist with language refinement, grammar checking, and clarity improvement. All content generated by the AI tools was critically reviewed, revised, and validated by the author(s). The author(s) take full responsibility for the integrity, originality, and accuracy of the content presented in this article.

REFERENCES

Ainy, H. Q., Supeno, & Ahmad, N. (2024). P*engembangan e-modul berbantuan flipbook digital untuk meningkatkan kemampuan problem solving siswa smp pada pembelajaran ipa* [development of e-modules assisted by digital flipbooks to improve middle school students' problem-solving skills in science learning]. *Jurnal Ilmiah Pendidikan Citra Bakti*, *11*(1), 102–115. https://doi.org/https://doi.org/10.38048/jipcb.v11i1.3090.

Angraini, L., Fitri, R., & Darussyamsu, R. (2025).

Profil kemampuan pemecahan masalah siswa sma mata pelajaran biologi [profile of high school students' problem-solving ability in biology subject]. *Bio-Pedagogi: Jurnal Pembelajaran Biologi*, *14*(1), 27–35. https://www.academia.edu/download/99311776/pdf.pdf

Araiza-Alba, P., Keane, T., Chen, W., & Kaufman, J. (2021). Immersive virtual reality as a tool to learn problem-solving skills. *Computers & Education*, *164*, 104121. https://doi.org/10.1016/j.compedu.2020.104121

Bambang, M., Pajria, P., Amelia, R., Apriliah, G. (2025). *Pendekatan deep learning dalam meningkatkan kemampuan pemecahan masalah dan motivasi belajar siswa pada materi komposisi fungsi* [deep learning approach to improving students' problem-solving ability and learning motivation in function composition material]. *Pedagogy*, *10*(4), 1519–1532. https://e-journal.my.id/pedagogy/article/view/7116/4506.

Cheng, K.-H., & Tsai, C.-C. (2019). A case study of immersive virtual field trips in an elementary classroom: Students' learning experience and teacher-student interaction behaviors. *Computers & Education*, *140*, 103600. https://doi.org/https://doi.org/10.1016/j.compedu.2019.103600

Cohen, J. (2013). *Statistical Power Analysis for the Behavioral Sciences*. Taylor & Francis. https://books.google.co.id/books?id=cIJH0lR33bgC

Elindra, R., & Rahma, A. (2019). *Pengaruh penggunaan model pembelajaran Problem Based Instruction (PBI) terhadap kemampuan pemecahan masalah matematika materi teorema Pythagoras di kelas VIII SMP Negeri 1 Padang Bolak Julu* [The effect of using the Problem Based Instruction (PBI) learning model on the mathematical problem-solving ability of the Pythagorean theorem material in class VIII of SMP Negeri 1 Padang Bolak Julu]. *Jurnal Mathedu (Mathematic Education Journal)*, *2*(1), 1–6.

Errabo, D. D., Paguio, A. J., & Enriquez, P. A. (2024). Epistemic fluency in virtual laboratories as flipped classroom's innovative learning delivery. *Journal of Research in Innovative Teaching and Learning*, *17*(2), 256–281. https://doi.org/10.1108/JRIT-03-2024-0052

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Gronlund, N. E., & Cameron, I. J. (2003). *Assessment of student achievement*. Pearson Education Canada. https://books.google.co.id/books?id=AV7OAAAACAAJ

Hattie, J. (2008). *Visible Learning: A Synthesis of Over 800 Meta-Analyses Relating to Achievement*. Taylor & Francis. https://books.google.co.id/books?id=ZO8jmUjQbs0C

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, *42*(2), 99–107. https://doi.org/10.1080/00461520701263368

Jiang, R. (2022). Understanding, Investigating, and promoting deep learning in language education: A survey on chinese college students' deep learning in the online EFL teaching context. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.955565

Jonassen, D. (2010). Learning to solve problems: A handbook for designing problem-solving learning environments. *Learning to Solve Problems: A Handbook for Designing Problem-Solving Learning Environments*, 1–437. https://doi.org/10.4324/9780203847527

Kushwaha, R. (2025). *Micro Schools: Redefining Education in the 21st Century*.

Levin, O. (2024). Simulation as a pedagogical model for deep learning in teacher education. *Teaching and Teacher Education*, *143*, 104571. https://doi.org/10.1016/j.tate.2024.104571

Marsel, F. O., & Fadilah, M. (2025). *Analisis kemampuan pemecahan masalah berdasarkan kemampuan awal dalam pembelajaran biologi di kelas x sma pembangunan laboratorium UNP* [analysis of problem solving ability based on initial ability in biology learning in class X of SMA Pembangunan Laboratorium UNP]. *Jurnal Ilmiah Pendidikan Biologi*, *11*(02), 390–398. https://online-journal.unja.ac.id/biodik

Mystakidis, S., Berki, E., & Valtanen, J. (2019). The patras blended strategy model for deep and meaningful learning in quality life-long distance education. *Electronic Journal of E-Learning*, *17*, 66–78. https://doi.org/10.34190/JEL.17.2.01

Nursita, N., Darsikin, D., & Syamsu, S. (2015). *Pengaruh model pembelajaran berbasis masalah terhadap kemampuan pemecahan masalah hukum newton pada siswa kelas X SMA Negeri 4 Palu* [the influence of problem-based learning model on newton's law problem-solving ability in grade X Students of SMA Negeri 4 Palu]. *JPFT (Jurnal Pendidikan Fisika Tadulako Online)*, *3*(2), 18. https://doi.org/10.22487/j25805924.2015.v3.i2.4472

OECD. (2024). *PISA 2022 Results (Volume III): creative minds, creative schools. OECD*. https://doi.org/https://doi.org/10.1787/765ee8c2-en

Polya, G., & Conway, J. H. (2004). *How to Solve It: A new aspect of mathematical method*. Princeton University Press. https://books.google.co.id/books?id=z_hsbu9kyQQC

Prince, M. J., & Felder, R. M. (2021). Inductive teaching and learning methods: definitions, comparisons, and research bases. *Journal of Engineering Education*, *95*(2), 123–138. https://doi.org/https://doi.org/10.1002/j.2168-9830.2006.tb00884.x

Rios, J. A., Ling, G., Pugh, R., Becker, D. M., & Bacall, A. N. (2020). Identifying critical 21st-century skills for workplace success: a content analysis of job advertisements. *Educational Researcher*, *49*(2), 80–89. https://doi.org/10.3102/0013189X19890600

Safari, S., & Khasanah, K. (2023). Assessment of student numeration literacy levels based on the 2021 national assessment data study. *RSF Conference Series: Business, Management and Social Sciences*, *3*, 90–98. https://doi.org/10.31098/bmss.v3i2.656

Santoso, H. B., Riyanti, R. D., Prastati, T., Triatmoko, F. A. H. S., Susanty, A., & Yang, M. (2022). Learners' online self-regulated learning skills in indonesia open university: implications for policies and practice. *Education Sciences*, *12*(7). https://doi.org/10.3390/educsci12070469

Savary, J. (2006). Why problem-based learning?

A case study of institutional change in undergraduate education. *Journal Problem-Based Learning*, *1*(1), 9–20. https://doi.org/10.7771/1541-5015.1002

Spector, J. M. (2014). Conceptualizing the emerging field of smart learning environments. *Smart Learning Environments*, *1*(1), 1–10. https://doi.org/10.1186/s40561-014-0002-7

Sugiyono, A. (2019). *Metode penelitian pendidikan: pendekatan kuantitatif, kualitatif, dan R&D* (Issue January).

Ukhtikhumayroh, & Rahmatsyah. (2020). E*fek Model Problem Based Learning (PBL) berbantuan alat praktikum terhadap kemampuan pemecahan masalah pada materi pokok Elastisitas dan Hukum Hooke* [The effect of the Problem Based Learning (PBL) model assisted by practical tools on problem-solving skills in the subject matter of Elasticity and Hooke's Law]. *INPAFI (Inovasi Pembelajaran Fisika)*, *8*(4), 83–88. https://rb.gy/gw1hng

Wolf, A., Tripanpitak, K., Umeda, S., & Otake-Matsuura, M. (2023). Eye-tracking paradigms for the assessment of mild cognitive impairment: a systematic review. *Frontiers in Psychology*, *14*(July), 1–24. https://doi.org/10.3389/fpsyg.2023.1197567

Wongchantra, P., Ongon, S., Junkaew, L., Sookngam, K., Praimee, U., Kaeongam, S., Pronyusri, T., Ritsumdaeng, P., & Wongchantra, K. (2022). The effect of environmental education learning for enhancing rivers management in the northeast of thailand using community-based learning. *Journal of Educational Issues*, *8*(1), 151. https://doi.org/10.5296/jei.v8i1.19544