JPPIPA 11(7) (2025)

Jurnal Penelitian Pendidikan IPA

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

Innovating Bacterial Cultivation Practicums to Promote Deep Learning: A Trial and Reconstruction of Student Worksheets (LKPD)

Afifi Mutiarani[1], Amprasto[1], Kusnadi[1]*

[1] Master of Biology Education Study Program, Universitas Pendidikan Indonesia, Dr. Setiabudi street No.229, Isola, Sukasari, Bandung City, West Java, indonesia 40154.

Received: May 01, 2025
Revised: June 16, 2025
Accepted: July 25, 2025
Published: July 31, 2025

Corresponding Author:
Kusnadi
kusnadi@upi.edu

DOI: 10.29303/jppipa.v11i7.11220

Abstract: This study aims to evaluate and test the feasibility of a student worksheet (LKPD) on bacterial cultivation and observation from a Natural Science textbook for grade X senior high school as a means to foster deep learning in the context of the deep learning. Using the Vee Diagram approach, the analysis shows that the LKPD contains several fundamental shortcomings—particularly in its unclear learning objectives, unsystematic procedures, and minimal space for reflection and data transformation. Through a self-conducted practicum trial, these identified weaknesses were indeed reflected in field implementation. Although the practicum was conducted, it faced issues such as overly dense colony growth, contamination, and inappropriate inoculation techniques, which led to suboptimal observations. This confirms that the structure and instructions in an LKPD significantly influence the success of experimental learning. Nonetheless, the activity revealed potential for further development. The practicum offers students the opportunity to experience scientific processes firsthand and understand the connection between biological concepts and real-life phenomena. With improved structure and approach, the LKPD can serve as an effective tool to support deep learning.

Keywords: Bacterial Cultivation; Deep Learning; Practicum; Reconstruction; Student Worksheet (LKPD)

Introduction

Practicum is an essential part of science learning because it provides students the opportunity to directly experience the scientific process: observing, questioning, experimenting, and concluding (Apeadido, Mensah, et al., 2024; Apeadido, Opoku-Mensah, et al., 2024). Practical work is an essential component of science teaching and learning, both for the aim of developing students' scientific knowledge and that of developing students' knowledge about science (Cairns & Areepattamannil, 2019; Kapici et al., 2020; Lin & Foong, 2024; Millar, 2004; Sood et al., 2023; Spaan et al., 2023). One of the key factors influencing the success of such experiences is the quality of the student worksheet (LKPD) used in the learning process (Indriyani & Firdaus, 2021; Martin, 2021; Nehyba et al., 2017)..

The LKPD must contain technical steps that encourage comprehensive and reflective scientific thinking. According to Novak & Gowin (1984), an ideal learning tool should help students build connections between theory, concepts, and practical experiences through a clear structure—such as the Vee Diagram approach they developed. Thus, LKPDs should not only guide activities but also help students construct meaning from what they do.

How to Cite:
Mutiarani, A., Amprasto, & Kusnadi. (2025). Innovating Bacterial Cultivation Practicums to Promote Deep Learning: A Trial and Reconstruction of Student Worksheets (LKPD). *Jurnal Penelitian Pendidikan IPA*, *11*(7), 387–395. https://doi.org/10.29303/jppipa.v11i7.11220

Unfortunately, in practice, teachers tend to use national textbook LKPDs directly without critically evaluating their content. Research shows that biology teachers face difficulties in effectively designing and planning practical lessons, have inadequate preparation prior to conducting them, and use inappropriate assessments of student achievement in biology practical work (Fadzil & Saat, 2020; Luciene & Rita, 2024; Sasse et al., 2025). As a result, many school practicals remain procedural and fail to foster deep conceptual understanding.

This issue becomes even more critical within the context of the 2025 Merdeka Curriculum, which emphasizes deep learning. This curriculum promotes learning as a conscious, meaningful, and joyful experience. It requires students not only to understand material but also to apply it in real-life contexts and reflect on its significance for their lives (Kementerian Pendidikan Dasar dan Menengah Republik Indonesia, 2025). Accordingly, teaching materials like the LKPD must go beyond procedural instructions and instead stimulate higher-order thinking, provide exploration space, and nurture context-driven curiosity (Kang & Kim, 2024; Peterson, 2020; Taramopoulos & Psillos, 2022).

Deep learning-oriented practicals expect student experiments to connect learners with the real world. This is essential because citizens in modern society need some understanding of the nature of scientific knowledge in order to evaluate claims that may affect their daily decisions (e.g., regarding health, diet, energy use) (Millar, 2004). The goal is not just to help students understand the natural world but to align their ideas and understanding with those of the scientific community.

In microbiology, for instance, students need to realize that bacteria are not just illustrations in books or animations, but real organisms present in their daily environments—on kitchen surfaces, hands, household tools, and other familiar places.

Unfortunately, the topic of bacteria is still frequently taught in a theoretical manner without providing students with direct, hands-on experience. Previous research found that biology textbooks for secondary school contained 7.4% undergeneralizations, 2.5% oversimplifications, 0.6% overgeneralizations, and 0.6% misidentifications, all of which negatively affect students' understanding of bacterial concepts (Novitasari et al., 2019). Several studies on microbiology education have shown that teachers tend to focus more on soft skills, while hard skills are still rarely addressed (Fibriana & Amalia, 2016). As a result, students lose the opportunity to truly grasp microbiology through scientific processes.

To equip students with a solid understanding of microbiology, it is necessary to renew learning models and strategies to make them more meaningful. The Kitchen Microbiology technique is one such effort to simplify microbiology practicums at the school level (Fibriana & Amalia, 2016). It involves the simple and effective preparation of microbial growth media using affordable materials commonly found in kitchens, traditional markets, or local supermarkets (Wilcoxon et al., 1999). This activity enables students to culture and observe microorganisms using tools and ingredients readily available in their environment. However, in Indonesia, such approaches are still rarely implemented, and no studies have yet evaluated the feasibility of this simplified practicum model within the context of secondary education.

Interestingly, one of the most recent editions of a Grade X science textbook has begun attempting to simplify bacterial cultivation activities in the form of a student worksheet (LKPD) designed for high school learners. This presents an opportunity to examine whether the activities outlined in the LKPD can be effectively implemented in schools, and which components need to be improved to support deep learning.

Based on this rationale, the current study aims to analyze one such LKPD using the Vee Diagram approach to assess how well it integrates theoretical concepts, biological principles, and experimental procedures. The LKPD was then independently trialed to observe its technical effectiveness and pedagogical potential. The results of the trial served as the basis for formulating recommendations to develop a more conceptually robust, technically feasible, and pedagogically aligned LKPD that supports the ideals on deep learning.

Method

This research is an exploratory study consisting of four main stages, namely: (1) analysis of the LKPD; (2) practicum trials based on the LKPD; (3) evaluation of the trial results as a basis for LKPD development, and; (4) reconstruction.

Analysis of the LKPD

The LKPD analyzed is sourced from the Natural Science textbook for Grade X Senior High School/Islamic Senior High School (SMA/MA). The LKPD contains bacterial cultivation and observation activities intended for students at X grade.

The analysis was conducted using the Vee Diagram approach Novak & Gowin (1984), which maps out key elements in a scientific activity, such as:

Focus Question: How well does the question stimulate scientific exploration?

Theory, Concepts, and Principles: Are they presented clearly and relevant to the activity?
Objects and Procedures: Consistency between the observed phenomena, work steps, and tools/materials.
Data Transformation and Knowledge Claims: To what extent is data processed into meaningful information?

The evaluation was carried out both qualitatively and quantitatively using a rubric based on these indicators. After the analysis, the LKPD was categorized according to Arikunto (2016) as shown in Table 1.

Tabel 1. LKPD Assessment Criteria

Skala	Indikator
80% - 100%	Excellent
70% - 79%	Good
60% - 69%	Fair
50% - 59%	Poor
0% - 49%	Very Poor

Practicum Trial Based on LKPD

After analysis, the LKPD was tested through a self-conducted practicum to observe whether the identified weaknesses also occurred during implementation. The practicum followed the exact procedures stated in the LKPD, without modifying the tools or materials.
Practicum activities included:
- Cultivating bacteria from environmental sources (e.g., ditch water) onto agar medium.
- Documenting colony growth over three consecutive days.
- Staining the colonies with methylene blue for microscopic observation.

Trial focus:
- Assessing the clarity and feasibility of the LKPD's instructions.
- Identifying technical and pedagogical obstacles during the activity.
- Observing the potential for scientific reflection if this practicum were conducted by students.

As an addition, the authors prepared two agar media—one with treatment (A) and one without treatment (B)—as a control. Medium B was used to detect contamination and identify which procedural steps may present weaknesses in sterilization.

Evaluation of Practicum Trial Results for LKPD Development

Trial data were analyzed descriptively. The aspects evaluated included:
- Obstacles encountered during the practicum steps.
- Quality of the observation results.
- Consistency between theory and practice.
- Potential for deep learning to emerge from the activity.

Reconstruction

Findings from the analysis and trials were used as a basis to formulate recommendations for improving the LKPD. These focused on enhancing instructional structure, refining methods, and adding reflective questions. A revised version of the LKPD was then created based on these improvements.

Result and Discussion

LKPD Analysis Results

The analysis of the used LKPD revealed several fundamental weaknesses in terms of structure, completeness of information, and pedagogical quality. The following table 2 summarizes the assessment:

Tabel 2. LKPD Scoring Summary

Aspect	Score	Description
Practicum objectives	0	Not stated at all
Focus question	3	Clear, relevant, and investigable through experimentation
Observed objects	3	Clearly identified and consistent with the focus question
Theories, principles, concepts	2	Mentioned but not clearly linked to procedures
Tools and materials	1	Incomplete specifications
Activity steps	1	Incomplete and unsystematic
Data transformation	2	Identified but not well-developed
Knowledge claims	2	Present but conceptually inaccurate or unsupported
Total Score	13/27	48% (Very Poor)

Key findings:
- Practicum objectives were not explicitly stated.
- Steps were disorganized and potentially confusing for students.
- Incomplete specifications of tools/materials could hinder learning.
- Theory and practice lacked clear connection.
- Very limited space for data transformation and reflective thinking.

This confirms that while the LKPD includes practical elements, it fails to guide students toward connecting theory, concepts, and real experiences effectively.

Findings from Practicum Trial

The practicum trial was conducted in accordance with the steps provided in the LKPD to assess whether the weaknesses identified also appeared during implementation. Several key observations were recorded:

Excessive Bacterial Growth (Blooming)

After following the LKPD instructions, bacterial growth on the medium showed very dense colony formation (blooming). As a result, the number of colonies could not be counted, and colony morphology could not be identified. **Figure 1** shows bacterial colonies after 24 hours of incubation.

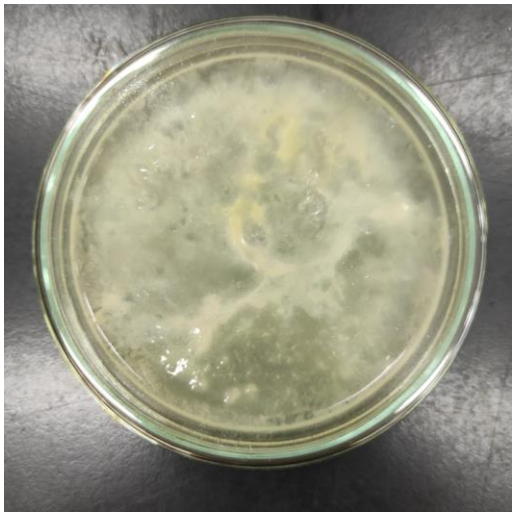

Figure 1. Bacterial Colonies from Ditch Water on the Second Day in Medium A

The likely cause of blooming is a mismatch in the selection of inoculation technique, medium, and sample type. The LKPD likely referred to the *spread method*, indicated by the instruction to drop ditch water onto the surface of solidified agar. However, the ditch water was neither diluted nor measured precisely (e.g., 1 drop or 0.1 ml via dropper).

Although the pour plate method is commonly used in microbiology quality control, it requires melting the culture medium before inoculation, which has limitations (Terrones-Fernandez et al., 2023). Ditch water contains a high bacterial concentration, requiring serial dilution and precise drop measurements to ensure controlled, observable colony growth (Hakvoort et al., 2020). Without dilution, microbial diversity in soil samples decreases (Yan et al., 2015).

This result confirms that inoculation technique selection is crucial. Using a pour method without dilution leads to colonies that cannot be observed effectively. In the context of learning, this risks students failing to identify bacterial colony morphology clearly.

Colonies Grew Inside the Agar

Sterilization of agar medium is meant to kill any microbes in the agar before use. However, the LKPD only mentioned "pan" as a sterilizing tool and did not specify time duration. The researcher used a steamer pot to sterilize for 10 minutes.

During observation, some colonies grew *within* the agar—indicating that the medium was not fully sterilized. This shows that although the agar could support bacterial growth, insufficient sterilization time led to unintended microorganism growth (contamination). This phenomenon is captured in **Figure 2**, suggesting that sterilization of the medium was not thorough.

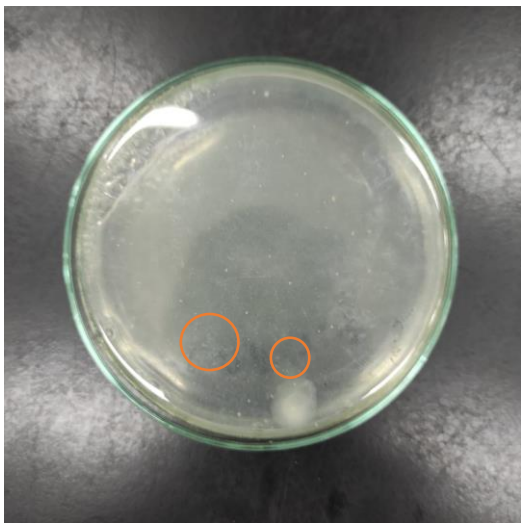

Figure 2. Bacterial Colonies Growing Within the Agar of Medium B

If an autoclave is available, all glass/metal tools and agar medium should be sterilized at 121°C for 15 minutes (Fibriana & Amalia, 2016; Lee et al., 2021). In educational settings, this contamination could hinder colony morphology identification, but also offer potential as a discussion point: why might unexpected organisms grow in sterile media?

Fungal Contamination on Petri Dishes

In **Figure 3**, Fungal colonies appeared even on media that were intended to be sterile.

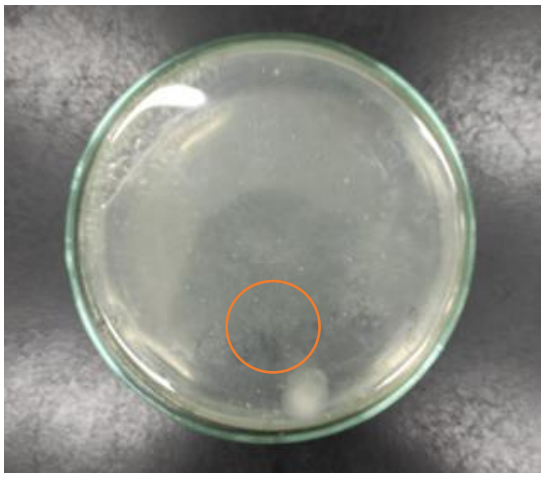

Figure 3. Fungal Colonies Growing on Agar Medium

The suspected cause is airborne contamination during the pouring of agar into petri dishes. The LKPD did not mention that this step should be done near a flame.

Ideally, pouring agar should occur near a fire source to prevent airborne contamination (Bykowski & Stevenson, 2020; Kaachra et al., 2024). In this trial, pouring was not performed near a flame, which likely allowed airborne spores to enter. This emphasizes the importance of aseptic techniques when working with microbiological media.

Microscopic Observation Only Showed Monococcus

The staining procedure yielded observable bacterial forms under the microscope, primarily monococcus (single round cells), as shown in Figure 4.

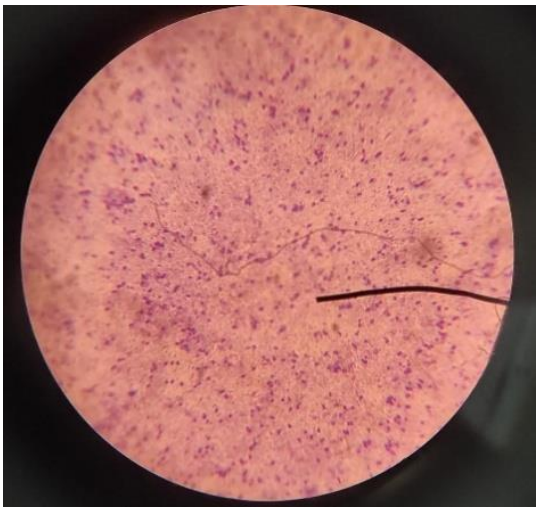

Figure 4. Results of Bacterial Staining

This uniform result likely stems from the use of a single-source sample, reducing the likelihood of encountering a variety of bacterial shapes. To improve pedagogical outcomes, future practices should include multiple sample sources (e.g., surfaces, hands, soil) to expose students to a broader range of bacterial morphologies.

Recommendations for LKPD Development

After completing both the analysis and practicum trial, the reconstruction of the LKPD was guided by several key recommendations. Two tables were used to summarize recommendations:

- **Table 2** addresses improvements based on the LKPD content analysis.
- **Table 3** addresses revisions derived from findings during the practicum trial.

Table 2. LKPD Reconstruction Recommendations Based on Content Analysis

Original LKPD Issue	Revised LKPD Solution
Practicum objectives not explicitly stated	Add clear learning objectives to guide student focus.
Instructions are unsystematic; tools/materials are incomplete	Improve procedural steps, including time durations, tools used, and clear sequencing.
Theory and concepts are present but not connected to practice	Insert reflective questions linking observations to biological concepts (e.g., bacterial structure, roles).
Data transformation and reflection are minimal	Include structured spaces for data transformation (e.g., growth tables, visual descriptions, interpretations).

Table 3. LKPD Reconstruction Recommendations Based on Practicum Trial Results

Problem Observed	Revision in Reconstructed LKPD
Excessive bacterial growth (blooming) due to undiluted ditch water and unclear inoculation volume	Add explicit instruction: use dropper to apply a fixed number of drops of ditch water (e.g., 1 drop per plate).
Bacterial colonies grew inside agar medium	Revise sterilization method: if no autoclave, steam tools and agar for 60 minutes to reduce contamination risk.
Fungal contamination appeared despite sterilization	Add instruction to pour agar near an open flame to minimize airborne contamination (aseptic technique).
Only one bacterial form observed after staining	Recommend using an additional bacterial source (e.g., a second sample from another surface) for morphological variety.

Based on these findings and revisions, a newly reconstructed LKPD was developed and included:

BIOLOGY PRACTICUM LKPD
MATERIAL: BACTERIA CULTIVATION AND OBSERVATION
LEVEL: GRADE X HIGHSCHOOL

LEARNING OBJECTIVES:
Students can observe and describe the shape of bacteria from the surrounding environment using simple coloring.
FOCUS QUESTIONS
What are the forms of bacteria in the surrounding environment and what influences their growth?

TOOLS AND MATERIALS

- 100 ml beef stock (Boil 150 gr of meat in 300 ml of water until reduced to ±100 ml, then strain with a strainer)
- 3 grams of colorless agar
- 50 ml of gutter water
- 2 Glass petri dishes
- 8 Clean paper
- 1 Cotton bud
- 1 Bunsen burner + matches
- 1 Glass bottle
- 10 sheets of cotton
- 1 Pot for steaming
- 2 Dropper pipettes
- 1 Clear tape
- 1000x magnification light microscope
- 1 Ose/small wire
- Immersion oil
- 100 ml Water
- 50 ml 96% Alcohol
- 50 ml Methylene blue
- 2 Object glass

WORK STEP 1: CULTIVATING BACTERIA

1. Wrap 2 petri dishes and cotton buds using three layers of clean paper. Make sure the entire surface is tightly covered.
2. Steam the petri dishes and cotton buds in a covered pot for 60 minutes to sterilize them.
3. Mix the agar powder and beef broth solution then put it in a heat-resistant glass bottle. Cover the end of the bottle with thick cotton.
4. Sterilize the agar-broth mixture by steaming for 60 minutes.
5. After the solution has cooled slightly, pour it into a petri dish until it is half the height of the dish, and do this process near a flame.
6. Let the medium harden at room temperature for approximately 30 minutes.
7. Take a sterile cotton bud, then rub it evenly on the surface of your unwashed hands.
8. Gently rub the cotton bud across the agar surface (use a zig-zag or streak pattern for even distribution).
9. Take another medium, then drip 1 drop of gutter water using a dropper on the surface of the medium.
10. Tape the edges of the petri dish using clear tape, then rewrap it with clean paper.
11. Store the petri dish in the shade and leave it for 1–3 days. Observe colony growth every day.

Bacterial Colony Observation Table

Day	Sample	Documen-tation	Colony Color	Colony Form	Colony Surface	Number of Colonies
1	Hand					
2	Hand					
3	Hand					
1	Gutter water					
2	Gutter water					
3	Gutter water					

DISCUSSION QUESTIONS

1. What are the characteristics of the bacterial colonies that you found?
2. What do you think are the factors that cause colonies to grow more or less?
3. Are there any organisms other than bacteria growing in your medium? If so, why do they grow in sterile media?
4. What effect does improper sterilization have on the results of your lab?
5. If you repeat this experiment by washing your hands first, what do you predict will happen?
6. If you were to do this experiment again with a different sample source (e.g., a lab benchtop), what do you predict will happen and why?

WORK STEP 2: BACTERIAL STAINING

1. Clean the slide using cotton wool soaked in 70% alcohol.
2. Place a drop of sterile water in the center of the slide.
3. Take a small ose/wire, then heat it over a flame until the tip glows red (sterile).
4. Once cool, gently streak the loop onto the bacterial colony in the petri dish.
5. Scratch the end of the loop/wire containing bacteria onto the surface of the object glass that has been dripped with water.
6. Air the object glass over the Bunsen burner until dry (avoid direct contact with the flame).
7. Drop the methylene blue solution and let it sit for ±5 minutes.
8. Rinse the object glass slowly using running water, then dry it again by airing it.
9. Add one drop of immersion oil, then observe under a microscope at 1000x magnification.

Bacterial Colony Observation Table

Microscope Magnification Documentation	Source of bacteria	Bacterial forms	Other characteristics found
	Hand		
	Gutter water		

DISCUSSION QUESTIONS

1. From the microscopic staining results, what shape of bacterial cells did you observe?
2. Can the shape of the bacterial cells you observe help you identify the type of bacteria? Explain your opinion.
3. What are the characteristics of bacteria that you can observe?
4. Why do bacteria turn colored after being given methylene blue? What bacterial organelles play a role?
5. Of the entire practicum process, which part do you think is most decisive for the success or failure of the observation? Explain why.

Potential for Deep Learning Identified

Although this practicum was conducted individually, there is strong evidence that the activity has significant potential to foster **deep learning**—

provided it is supported by the right tools and instructional approach.

One major strength lies in the use of **simple and accessible equipment**, such as household items like electric steamers, which allow students to conduct microbiological experiments using locally available materials. Despite the simplicity of the tools, the bacteria successfully grew, were cultured, and even served as viable samples for further microscopic observation.

Figure 4 (previously referenced) demonstrates a successful result from the staining procedure—an image of bacterial cells that were visibly identifiable under the microscope. This shows that bacterial culturing can be done effectively in modest, everyday environments, reinforcing the idea that meaningful science learning does not always require sophisticated lab setups. Research shows that microbiology learning that provides hands-on experience and is connected to students' lives can be more meaningful to students (Kulesza et al., 2022; Sasse et al., 2025; Waring-Sparks et al., 2024). The improved worksheet is expected to be a guide that can facilitate students to get meaningful learning.

However, the approach used in this practicum still has limitations. The experiment only used **one sample source**, limiting student exploration and comparison. This restricts opportunities for students to design their own investigations, such as testing bacteria presence on various surfaces (e.g., sink handles, doorknobs, desks).

Nevertheless, this activity offers substantial opportunities for deep learning, including:

- **Conscious learning** (*berkesadaran*): The staining process opens opportunities to explore cell wall structures and links to bacterial classification if students are guided with critical questions.
- **Meaningful learning** (*bermakna*): Students directly observe the bacterial forms growing from their own environment, making abstract microbiological concepts tangible and relevant.
- **Joyful learning** (*menggembirakan*): Unexpected findings—such as the growth of fungi in "sterile" media—can serve as engaging discussion starters that provoke curiosity and inquiry.

Conclusion

This study finds that the LKPD-based practicum can indeed support conscious, meaningful, and joyful learning, especially if the LKPD is further developed and refined. However, there are several limitations in this research: (1) The practicum was trialed individually, not in a full classroom setting, so it does not yet capture actual student responses or classroom dynamics; (2) The study ended at the recommendation phase; the revised LKPD has not yet been tested with students to assess its effectiveness in promoting deep learning; (3) Future studies are encouraged to: (1) Involve students directly in the trial phase, allowing researchers to observe both cognitive and emotional responses; (2) Measure deep learning outcomes using reflective questions, critical thinking tasks, and conceptual mapping before and after the practicum.

Author Contributions

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

Funding

No external funding

Conflicts of Interest

The authors declare no conflict of interest

References

Apeadido, S., Mensah, G. O., & Opoku-Mensah, D. (2024). The Impact of Practical Experiential Learning on Shaping High School Students' Attitudes Towards Biology. *Journal of Science Education Research*, *8*(2), 108–119. https://doi.org/10.21831/jser.v8i2.76369

Apeadido, S., Opoku-Mensah, D., & Mensah, G. O. (2024). Enhancing Science Process Skills and Academic Performance in Biology: The Impact of Practical Work. *Integrated Science Education Journal*, *5*(1), 34–41. https://doi.org/10.37251/isej.v5i1.854

Arikunto, S. (2016). *Prosedur Penelitian: Suatu Pendekatan Praktik*. Pt. Rineka Cipta.

Bykowski, T., & Stevenson, B. (2020). Aseptic Technique. *Current Protocols in Microbiology*, *56*(1). https://doi.org/10.1002/cpmc.98

Cairns, D., & Areepattamannil, S. (2019). Exploring the Relations of Inquiry-Based Teaching to Science Achievement and Dispositions in 54 Countries. *Research in Science Education*, *49*(1), 1–23. https://doi.org/10.1007/s11165-017-9639-x

Fadzil, H. M., & Saat, R. M. (2020). Exploring Secondary School Biology Teachers' Competency in Practical Work. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 117–124. https://doi.org/10.15294/jpii.v9i1.21477

Fibriana, F., & Amalia, A. V. (2016). Potensi kitchen microbiology untuk meningkatkan keterampilan teknik hands-on dalam pembelajaran mikrobiologi. *Unnes Science Education Journal*, *5*(2),

1210–1216. http://journal.unnes.ac.id/sju/index.php/usej

Hakvoort, H., Bovenkamp, E., Greenwood-Quaintance, K. E., Schmidt-Malan, S. M., Mandrekar, J. N., Schuetz, A. N., & Patel, R. (2020). Imipenem-Relebactam Susceptibility Testing of Gram-Negative Bacilli by Agar Dilution, Disk Diffusion, and Gradient Strip Methods Compared with Broth Microdilution. *Journal of Clinical Microbiology*, *58*(10). https://doi.org/10.1128/JCM.00695-20

Indriyani, Z. S., & Firdaus, R. M. (2021). *The Influence of Using Students Worksheet, School Environment and Learning Motivation on Social Studies Learning Achievement*. https://doi.org/10.2991/assehr.k.210413.092

Kaachra, A., Suri, A., & Kumar, S. (2024). An improved and convenient petri plate-based method for studying the root growth of plants. *MethodsX*, *12*, 102505. https://doi.org/10.1016/j.mex.2023.102505

Kang, J., & Kim, J. (2024). Exploring the predictiveness of curiosity and interest in science learning in and after class. *Journal of Research in Science Teaching*, *61*(8), 1821–1857. https://doi.org/10.1002/tea.21920

Kapici, H. O., Akcay, H., & de Jong, T. (2020). How do different laboratory environments influence students' attitudes toward science courses and laboratories? *Journal of Research on Technology in Education*, *52*(4), 534–549. https://doi.org/10.1080/15391523.2020.1750075

Kementerian Pendidikan Dasar dan Menengah Republik Indonesia. (2025). *Naskah Akademik Pembelajaran Mendalam Menuju Pendidikan Bermutu untuk Semua*. Pusat Kurikulum dan Pembelajaran Kemendikdasmen Republik Indonesia.

Kulesza, A. E., Imtiaz, S., & Bernot, K. M. (2022). Building Connections to Biology and Community through Service-Learning and Research Experiences. *Journal of Microbiology & Biology Education*, *23*(3). https://doi.org/10.1128/jmbe.00082-22

Lee, J., Kim, H.-S., Jo, H. Y., & Kwon, M. J. (2021). Revisiting soil bacterial counting methods: Optimal soil storage and pretreatment methods and comparison of culture-dependent and -independent methods. *PLOS ONE*, *16*(2), e0246142. https://doi.org/10.1371/journal.pone.0246142

Lin, G. S. S., & Foong, C. C. (2024). Integrating hands-on practical and reflective feedback in teaching dental materials science to undergraduate dental students. *European Journal of Dental Education*, *28*(3), 816–824. https://doi.org/10.1111/eje.13011

Luciene, M. P. Q., & Rita, R. (2024). Aquaponics and art in education: Encouraging sustainability, ecological awareness, and creative expression in high school. *International Conference Czech Republic and Lusophonic Countries 2024*, 63–64. https://doi.org/10.24132/ZCU.2024.12426.63-64

Martin, A. M. (2021). Instructor qualities and student success in higher education online courses. *Journal of Digital Learning in Teacher Education*, *37*(1), 65–80. https://doi.org/10.1080/21532974.2020.1815106

Millar, R. (2004). *The role of practical work in the teaching and learning of science*.

Nehyba, K., Miller, S., Connaughton, J., & Singer, B. (2017). Assessing student clinical learning experiences. *The Clinical Teacher*, *14*(4), 247–250. https://doi.org/10.1111/tct.12557

Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. Cambridge University Press.

Novitasari, C., Ramli, M., & Karyanto, P. (2019). Content analysis of misconceptions on bacteria in the biology textbook of high school. *Journal of Physics: Conference Series*, *1157*, 022076. https://doi.org/10.1088/1742-6596/1157/2/022076

Peterson, E. G. (2020). Supporting curiosity in schools and classrooms. *Current Opinion in Behavioral Sciences*, *35*, 7–13. https://doi.org/10.1016/j.cobeha.2020.05.006

Sasse, H., Weber, A. M., Reuter, T., & Leuchter, M. (2025). Teacher Guidance and On-the-Fly Scaffolding in Primary School Students' Inquiry Learning. *Science Education*, *109*(2), 579–604. https://doi.org/10.1002/sce.21921

Sood, S., Fang, S., Wang, A. C., Luong, T., Kim, J. K., Sinha, A., Jerome, J., & Rafailovich, M. H. (2023). Polystyrene Laboratory Analysis: A Hands-On Experience for High School Students to Determine the Molecular Weight of Polystyrene Through Spin Casting. *Journal of Chemical Education*, *100*(2), 900–906. https://doi.org/10.1021/acs.jchemed.2c00987

Spaan, W., Oostdam, R., Schuitema, J., & Pijls, M. (2023). Thinking-back-and-forth in practical work experienced by students: identifying evidence-informed characteristics of good practices in secondary education. *Research in Science & Technological Education*, 1–18. https://doi.org/10.1080/02635143.2023.2268005

Taramopoulos, A., & Psillos, D. (2022). Developing procedural knowledge in secondary education students. *Journal of Physics: Conference Series*, *2297*(1), 012010. https://doi.org/10.1088/1742-6596/2297/1/012010

Terrones-Fernandez, I., Casino, P., López, A., Peiró, S., Ríos, S., Nardi-Ricart, A., García-Montoya, E., Asensio, D., Marqués, A. M., Castilla, R., Gamez-Montero, P. J., & Piqué, N. (2023). Improvement of

the Pour Plate Method by Separate Sterilization of Agar and Other Medium Components and Reduction of the Agar Concentration. *Microbiology Spectrum*, *11*(1). https://doi.org/10.1128/spectrum.03161-22

Waring-Sparks, A. L., Waring-Sparks, R. A., Darner, R., & Mortimer, N. T. (2024). Advanced biology students' individual conceptions of scientific researchers after participating in biomedically relevant CRE. *Journal of Microbiology & Biology Education*, *25*(3). https://doi.org/10.1128/jmbe.00183-23

Wilcoxon, C., Shand, S. M., & Shand, R. F. (1999). Kitchen Microbiology (It's Easier than You Think!). *The American Biology Teacher*, *61*(1), 34–38.

Yan, Y., Kuramae, E. E., Klinkhamer, P. G. L., & van Veen, J. A. (2015). Revisiting the Dilution Procedure Used To Manipulate Microbial Biodiversity in Terrestrial Systems. *Applied and Environmental Microbiology*, *81*(13), 4246–4252. https://doi.org/10.1128/AEM.00958-15