

Improving Cognitive Engagement and Achievement in Biology through PBL: A Mixed Methods Exploration

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ABSTRACT

This study investigates the impact of Problem-Based Learning (PBL) on enhancing student understanding of high school biology, specifically focusing on the topic of biodiversity. This research is grounded in constructivist and inquiry-based pedagogical theory, addressing common issues of low engagement and underachievement in biology classrooms. As Maldivian schools transition toward more active learning paradigms, this study offers timely insight into how student-centered strategies such as PBL might improve both comprehension and motivation. A mixed methods approach was used, involving a single Grade 12 student selected through purposive sampling. Quantitative data were gathered using pre- and post-tests to measure changes in conceptual understanding and engagement. Qualitative data emerged from interviews, reflective discussions, and analysis of student work. The results showed improved student performance, with a 20% increase in post-test scores. The participant demonstrated an enhanced ability to apply biological concepts in unfamiliar contexts. Beyond academic gains, the PBL strategy also fostered metacognitive skills, critical thinking, and development of transferable skills. Student reflections highlighted increased engagement and a deeper connection to the learning process. Despite the single-subject scope and limited sample size, the findings provide compelling evidence supporting the effectiveness of PBL in promoting meaningful, student-centered learning in biology classrooms. The study suggests broader implementation of PBL in Maldivian classrooms and contributes to the literature advocating innovative, inquiry-based approaches in science instruction.

Keywords: Problem-Based Learning (PBL), biology education, constructivism

INTRODUCTION

Biology is an important subject for students who intend to pursue careers in science. However, many high school students do not find biology enjoyable because they often experience it as a subject that requires memorizing a large volume of information. This emphasis on memorization can lead to boredom, reduced concentration, and weaker interest in learning biology (Husna et al., 2023; Wang et al., 2023).

Memorizing concepts without understanding is insufficient because students are then unable to apply knowledge to new scenarios, which is a central goal of science education (Kaminske et al., 2020). Surface-level memorization restricts the deeper knowledge needed for real conceptual change (McDaniel et al., 2022). This transfer gap can persist even in courses designed around active learning and conceptual thinking when students' memorization-based approaches override the intended deep-learning goals (McDaniel et al., 2022).

Transfer of biological concepts requires learning strategies that move students beyond memorization and toward applying knowledge in unfamiliar contexts. This study therefore examines Problem-Based Learning (PBL), a student-centered strategy designed to engage learners in sustained inquiry and deeper learning rather than surface learning (Abugri et al., 2026).

PBL in high school biology has often been studied through short-term quasi-experimental designs, while fewer studies combine quantitative and qualitative approaches (Nurhasanah et al., 2024; Nwankwo et al., 2024). As a result, limitations remain in understanding the transferability of findings and the specific mechanisms through which PBL may shift students away from rote memorization (Akçay & Benek, 2024; Uliyandari et al., 2021).

Biology education faces a persistent tension between surface-level learning and the deep conceptual understanding needed to solve real-world problems and sustain interest in the subject (Honra & Monterola, 2026; Uluçınar, 2023). In the Maldives, this concern is reflected in low achievement in A Level biology; in 2017, only 22% of candidates passed the subject (Ministry of Education, 2017). This combination of limited conceptual engagement and low attainment creates a need to examine learning approaches that may help students connect and apply biological ideas.

The Maldives national curriculum calls for incorporating PBL into lessons to make them interactive (National Institute of Education, 2014). While PBL is a widely recognized student-centered approach that fosters authentic student engagement, its effect on cognitive engagement within biology education remains underexplored (Honra & Monterola, 2026). Furthermore, research on problem solving as a fundamental learning outcome in biology remains limited (Nigussie et al., 2025). Moreover, many existing studies use homogeneous designs (Trullàs et al., 2022). Fewer studies have applied mixed methods specifically to

examine whether PBL shifts students from surface-level learning toward abstract concept building (Adah Miller et al., 2025; Honra & Monterola, 2026). This study examines changes in one Grade 12 student's understanding of biodiversity following participation in Problem-Based Learning. Following with the research question: What changes in one Grade 12 student's understanding of biodiversity are observed following participation in Problem-Based Learning?

A key significance of the current study is its contextual specificity. It adds case-based evidence from a Maldivian classroom to research examining how PBL may support conceptual understanding, higher-order thinking, and active participation in biology lessons. Because PBL is flexible rather than one-size-fits-all, evidence from one curriculum setting does not automatically transfer to another (Ivaningtias et al., 2024).

This study is grounded in constructivist and inquiry-based learning theories, which view learning as an active process involving questioning, investigation, evidence use, and reflection (Antonio & Prudente, 2023). PBL applies these principles by placing authentic problems at the center of learning. Through this approach, students identify what they need to know, direct aspects of their own learning, and engage with evidence while the teacher acts as a facilitator (Morris, 2025). In the context of this study, the biodiversity topic demonstrates how these theories can be portrayed within local classroom realities. Therefore, the study contributes not only to understanding whether PBL is effective, but also to explaining how constructivist and inquiry-based teaching can be meaningfully localized in biodiversity education (Iwan et al., 2025; Smith et al., 2022).

REVIEW OF LITERATURE

Origins of Problem-Based Learning

Problem-Based Learning (PBL) was pioneered in the mid-twentieth century at a medical school in Canada as an alternative to traditional lecture-based instruction (Hill & Smith, 2005). Although the approach first took hold in medical education, it has since expanded into general education settings, where it is now applied across disciplines and grade levels (Hill & Smith, 2005).

PBL is defined by Ram et al. (1995) as “a constructivist pedagogy in which students learn science and develop critical thinking skills by solving real-world problems in small groups.” Two features of this definition distinguish it from traditional classroom practices: the learning task is an authentic problem, and students drive the investigation while the teacher facilitates. Hence, PBL activities are student-centered, integrating real-world problem solving in ways that conventional, subject-bound instruction does not (Rubrica, 2019).

The rationale for PBL rests on constructivism, which holds that learners build new understanding by interpreting ideas and information in relation to what they already know and believe (Richardson, 2003). PBL translates this principle into practice by asking students to construct knowledge through problem solving rather than receive finished explanations (Ram et al., 1995). This orientation supports its use in high school science because learners must connect prior knowledge, evidence, and new concepts while developing solutions to authentic problems.

Implementing Problem-Based Learning

Vincent R and Lyons (2015) outline six steps for implementing PBL:

1. Identify the intended learning outcomes and prepare assessments aligned with those outcomes
2. Design the scenario: an authentic, real-world problem embedded in the lesson, constructed so that it generates discussion among students
3. Introduce PBL to students, communicating expectations, assessments, rubrics, and timelines
4. Allow students to research the topic, cover the syllabus specifications, and create a product from their research
5. Have students present their research and their proposed solutions to the problem
6. Evaluate students' work

PBL and cognitive improvement

Recent meta-analyses suggest that PBL produces significant cognitive benefits, although the effects are far from uniform. A meta-analysis of 25 studies found a large overall effect of PBL on critical thinking, moderated by teaching method and subject (Lu et al., 2025). However, a synthesis of 50 studies reported a moderate effect with high heterogeneity and little benefit from short interventions (Liu & Pásztor, 2022). At the secondary level, a meta-analysis of 11 studies reported a large positive effect of PBL on science achievement (Funa & Prudente, 2021). High school biology studies show a similar pattern: PBL improved achievement and retention among students in Nigeria (Usman et al., 2023), and Indonesian students improved in argumentation and critical thinking, but only with metacognitive prompting (Marthaliakirana et al., 2022). This evidence is not uniformly positive, however. A meta-analysis of first-year medical students found no significant advantage of PBL over conventional instruction (Manuaba et al., 2022). Moreover, engagement scores in PBL tutorials show no consistent relationship with academic achievement (Kassab et al., 2023). Notably, most studies of PBL concern higher education, while studies conducted in high schools are short-term quasi-experiments in single schools.

PBL and conceptual understanding

PBL is expected to deepen conceptual understanding, and recent secondary-school studies provide partial support for this claim. An intervention integrating STEM and PBL in Grade 11 biology reported gains in conceptual understanding, although it used a limited pretest–posttest sample (Funa, 2026). Similar gains have been reported in Grade 11 physics (Damanik et al., 2024). However, effect sizes vary across studies, samples are often small, and researcher-developed instruments may measure recall rather than conceptual understanding. Outcomes may also depend on teacher scaffolding; without metacognitive prompts, students have demonstrated weaker argumentation and critical thinking (Marthaliakirana et al., 2022). Because much of this evidence comes from single-design studies, further mixed methods research is needed to examine cognitive engagement and conceptual understanding in specific high school biology contexts.

Conceptual difficulties in biodiversity learning

Biodiversity is a major topic in International Advanced Level (IAL) Biology and is addressed in Unit 2 of the programme. It is defined by Fullick and Sochacki (2018) as the variety of organisms, including the species and genes found in a region. Its interrelated subtopics include biodiversity and endemism, measuring biodiversity, adaptation to a niche, gene pools and genetic diversity, speciation, and conservation. Because IAL examination questions cover most of these subtopics, students must understand the concepts fully and relate them to one another.

Recent research shows that biodiversity is a difficult concept because it spans multiple interacting dimensions. Among 10th-grade students' responses to biodiversity items, 29.41% reflected misconceptions and 20.59% were unanswered (Ilhamdi et al., 2022). A diagnostic survey found that just 7.4% of students fully understood biodiversity, with misconceptions arising when comparing genetic, species, and ecosystem diversity (Purba et al., 2026). Since biodiversity conceptions are stable and resistant to correction, transmission-based teaching is unlikely to be sufficient, requiring a more student-centered approach such as PBL.

Theoretical Framework

This study is grounded in inquiry-based learning (IBL), a learner-centered approach in which learners construct knowledge through questioning, investigation, interaction, reflection, and the application of ideas to meaningful problems. The framework is historically associated with Dewey's emphasis on experience and learning through inquiry. It is also consistent with constructivist principles, which view learners as active participants in the construction of knowledge (Suryati et al., 2024).

PBL is an important approach within IBL because it engages learners with authentic problems. It encourages them to ask questions, investigate evidence, collaborate, develop

explanations, and apply possible solutions. Recent evidence indicates that IBL can improve learning outcomes, although its effectiveness may depend on factors such as educational level, instructional design, and learner engagement (Harleni et al., 2025).

The framework guided the data collection process by directing attention to the learner's questions, participation, interactions, investigations, problem-solving activities, and reflections. Data were therefore collected from the learner's experiences and observable engagement with the inquiry-based activities rather than from final outcomes alone. This approach is consistent with Tshering and Yangden (2021), who examined inquiry-based learning using achievement tests, questionnaires, and classroom observations.

The framework guided the analysis of data, as the participant's responses and observed learning process were examined according to the six-step inquiry-based learning model proposed by Vincent R and Lyons (2015). The analysis focused on evidence of the learner's movement through the stages of problem identification, questioning, investigation, collaboration, reflection, and the development or application of solutions.

During interpretation, the findings were understood in relation to constructivist learning principles. Changes in the learner's responses and participation were interpreted as evidence of how she constructed meaning through experience, inquiry, and reflection.

RESEARCH DESIGN

An action research design was adopted to answer the research question. Sagor (2000) defines action research as a disciplined process of inquiry conducted by and for those taking action. This fits the current study as the study is conducted by the teacher researcher to determine whether PBL improves students' understanding of biodiversity. Action research may be individual, collaborative, school-wide or district-wide (Mertler, 2017). This study follows the individual form, as the research was carried out by the teacher herself.

The study used a mixed methods approach. Quantitative data came from pre- and post-assessments administered before and after the PBL lessons, and the scores were compared descriptively. Qualitative data came from the student's reflections after each task, content analysis of her written work and assessment responses, and observations of her presentations.

The single-student sample and the teacher-researcher's dual role limit generalizability and carry a risk of bias. However, individual action research aims to improve the practitioner's own practice, and validity was maximized through triangulation, with conclusions drawn only where qualitative and quantitative sources converged; through repeated measurements across the intervention; and through reflexivity, with the teacher-researcher monitoring her dual role (Johnson et al., 2020). A detailed description of the context, intervention, and data sources further supports transferability to comparable settings (Kakar et al., 2023).

The target population was high school biology students. The sample consisted of one Grade 12 biology student selected through criterion-based purposive sampling, which aligned with the research aim and supported the trustworthiness of the findings (Campbell et al., 2020). Only one student was selected because data were collected during the examination period and the COVID-19 pandemic, when student availability and access were substantially restricted. Single-participant research is appropriate when one participant can be studied intensively and repeatedly over time because it can provide detailed, context-specific insight, although the findings should not be treated as statistically generalizable to all students (Sandars, 2009).

A pre-assessment and post-assessment were used to gather quantitative data and determine whether the student's understanding improved after the PBL lessons. Each assessment contained seven items covering the biodiversity learning objectives, and the items were reviewed by a subject teacher for content validity before administration (Moskal, 2002). Both assessments were scored using a common marking scheme, and a sample of scripts was re-marked by a subject teacher to confirm scoring consistency and reliability (Moskal, 2002). Sample items are provided in Appendix A.

A semi-structured interview was used to collect qualitative data on the student's cognitive engagement and understanding. The interview prompts were derived from the research question and reviewed by an expert following the recommended phases for developing a rigorous interview guide (Kallio et al., 2016). Open-ended questions were used to generate flexible, in-depth responses (Kallio et al., 2016). Interview findings were triangulated with the pre- and post-assessment results and with analyses of the student's written tasks and reflections. Before the PBL lessons were conducted, written consent was obtained from the participant. The participant was fully informed of the purpose of the research, how it would be conducted, and her role in the study, all of which were stated in the consent form.

A pre-assessment was administered through an online platform and sent to the student via Viber. The student was given 20 minutes to complete and return it. The assessment was marked, and the answers were analyzed. Five PBL lessons on biodiversity were then conducted on different days over a four-week period. After each lesson, the student was assigned a task to complete for the next class, where she presented her work. During these presentations, data were collected on her knowledge of the topic, the quality of her work, and her presentation skills. Each presentation was followed by a reflective discussion that generated qualitative data. Finally, a post-assessment was administered, marked, and analyzed using the same procedures as the pre-assessment.

Because all assessments were completed and submitted online, the researcher could not observe the classroom dynamics, body language, or immediate reactions that would accompany face-to-face administration, and the reduced visibility of non-verbal cues in

online settings can limit what the researcher perceives during data collection (Eklund & Isotalus, 2024). The live presentation sessions in which the student presented her tasks helped offset this by allowing direct observation of her explanations and responses during the study.

Because the researcher served as both teacher and data collector, several safeguards were used to reduce bias. A second teacher independently marked the assessments, and the two sets of scores were compared before the results were finalized. The researcher also kept a reflective journal throughout the study to record expectations and assumptions, supporting reflexivity in the qualitative analysis (Johnson et al., 2020). Findings from the assessments, presentations, and reflective discussions were triangulated, and interpretations from the reflective discussions were verified with the participant through member checking before inclusion in the analysis.

The pre- and post-assessment marks were analyzed using descriptive statistics in Microsoft Excel, and the results were presented in tables and graphs. The qualitative data from the reflective discussions and student work were analyzed using thematic analysis. The analysis followed a systematic coding process. First, the reflective discussions were transcribed and typed in Microsoft Word. Second, the transcripts were read several times to gain familiarity with the data. Third, initial codes were generated by identifying and labeling key terms and meaningful segments in the text. Fourth, related codes were grouped into themes, and the themes were reviewed against the data to ensure that they were internally consistent and supported by the evidence. Finally, each theme was defined, named, and illustrated with excerpts from the transcripts. This step-by-step approach follows the systematic thematic analysis process recommended in recent methodological guidance (Byrne, 2022; Naeem et al., 2023).

To increase the trustworthiness of the study, the coding process was checked by a second reviewer, and the researcher's interpretations were triangulated with the assessment scores and student work (Kakar et al., 2023). Illustrative quotes are used in the findings to ground each theme in the participant's own words.

Ethical considerations

The student received written and oral information about the study before the lessons and the reflective discussions and interview, including its purpose, procedures, and use of data. Participation was voluntary, and informed consent was obtained. The student could refuse to answer any question or withdraw from the study at any time without penalty. Confidentiality was maintained by removing identifying information. Data were stored securely and used only for research purposes. Data were reported in a way that protected the student from identification. Interview recordings and notes were handled confidentially.

Reliability and Validity

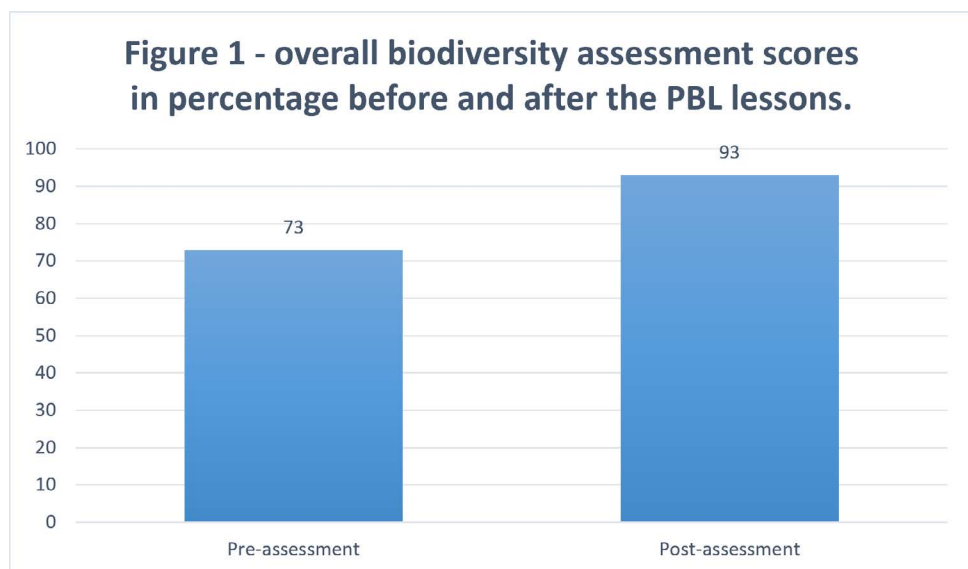
The interview questions were derived from the theoretical framework to ensure that they addressed the research question. The pre- and post-assessments drew items directly from Edexcel examination papers, aligning the test content with the assessed curriculum and supporting content validity. Assessment scores were triangulated with qualitative data from the reflective discussions, interview, and student work, thereby strengthening the credibility of the conclusions (Kakar et al., 2023b).

Because the study involved a single participant, reliability was addressed through consistency in measurement and analysis. Both assessments were scored using a common marking scheme, and a second high school biology teacher independently marked the tests to reduce the influence of researcher bias. A second reviewer also checked the coding of the qualitative data.

FINDINGS

Quantitative data

The student's overall score improved from 73% in the pre-assessment to 93% in the post-assessment, a gain of 20 percentage points (Figure 1). Because the study involved a single participant, these results are reported descriptively and are not subjected to inferential statistical analysis. Therefore, no claims of statistical significance are made.



An item-level comparison shows where improvement occurred. In both assessments, the student scored well on lower-level items testing factual knowledge of biodiversity, such as species concept, adaptation and endemism. On higher-level items requiring the connection of multiple biodiversity concepts, the student scored 2/6 in the pre-assessment but 5/6 in the post-assessment, an improvement of 50%. The largest gains were on items addressing speciation, which improved from 30% to 80%. These descriptive patterns suggest that the student was better able to link different biodiversity concepts after PBL lessons, consistent with the qualitative findings below.

Qualitative data

The qualitative data came from the student's presentations, written work, reflections, and interview. Following the systematic coding process described in the data analysis section, the interview transcript, reflective discussion records, and student work were read repeatedly, initial codes were generated, and related codes were grouped into candidate themes. Four themes were identified and reviewed against the data to confirm that they were supported by the evidence: understanding of the topic, metacognitive abilities, development of transferable skills, and attitude.

During coding, the initial codes clustered into four recurring groups. Codes such as "links concept to context," "gives relevant examples," and "makes inferences" formed the theme of understanding the topic; codes such as "identifies own misconceptions" and "relates learning to local context" formed metacognitive abilities; codes such as "learns new software features," "phrases searches," and "cites sources" formed the development of transferable skills; and codes such as "shows interest" and "prefers this way of learning" formed attitude. Each theme is described below with supporting evidence and the student's own words.

Understanding the topic

This theme captures the student's grasp of biodiversity concepts and her ability to connect and apply them. In the pre-assessment, she struggled to connect concepts and relate content to contextual questions, which cost her marks. In the post-assessment, she integrated multiple concepts and related them to context, and her score rose from 73% to 93%. Her presentations showed the same pattern: she produced information-rich work, explained most research questions clearly, and linked relevant examples to the content taught in class. From this understanding, she made inferences, judgments, and suggestions on biodiversity issues.

"Finding information on my own to do this task was very helpful. I was able to read a lot of information, unlike the notes given by Miss. Also, when you give notes, students won't bother reading more about it."

Learning biodiversity through real-world scenarios made the topic more meaningful to her and encouraged her to take responsibility for her own learning, which may explain why she read beyond what was assigned. This is consistent with research showing that PBL encourages a deep rather than surface approach to learning by requiring students to engage with information at multiple levels and in greater depth than traditional teaching (Fox, 2010). Because exam questions are often set in unfamiliar contexts, PBL can broaden students' knowledge so they can answer questions based on contexts they have not seen before.

Metacognitive abilities

This theme captures the student's awareness of her own learning and thinking. Metacognition refers to thinking about thinking, becoming aware of one's own learning and growth (Flavell, 1979). The student related what she learned to biodiversity in the Maldives, identifying similar environmental conditions in the Maldives and Australia, and reasoned about why animals in the Maldives show particular adaptations. She recognized the importance of conserving Maldivian biodiversity and proposed solutions to its decline, showing comprehension that supported critical thinking and problem solving.

“While researching the peppered moth and the Industrial Revolution, I realized I had a few misconceptions about mutation and natural selection.”

Her ability to identify her own misconceptions through research is direct evidence of metacognitive growth. This finding aligns with research showing that PBL improves students' metacognitive abilities alongside their understanding of a topic (Jannah et al., 2025).

Development of transferable skills

This theme captures the new skills the student acquired during the PBL lessons. Transferable skills are defined by the Organisation for Economic Co-operation and Development (OECD) as “the bundle of knowledge, attributes and capacities that can be learned and that enable individuals to successfully and consistently perform an activity or task and can be built upon and extended through learning” (Pearson Education Limited, 2020). The student learned to search for relevant information, phrase searches to obtain the results she needed, cite sources, separate syllabus content from extra information, and align it with learning outcomes.

“I didn't know how to use some features of PowerPoint before, like how to send back pictures. To do this presentation, I googled and learnt it.”

She also learned to use features of Microsoft applications by searching the web. The PBL tasks required her to move beyond her existing skills and develop research, digital-literacy, critical-thinking, and problem-solving practices that may be useful in future study

and work. This finding is consistent with research showing that PBL can motivate learning about sustainability and support transferable-skill development (Overton & Randles, 2015). In the present case, these skills also helped the student organize information and construct contextually relevant answers in biology.

Attitude

This theme captures the student's engagement and disposition toward learning biology. Although the student was in high school, she appeared uninterested and unmotivated in face-to-face classes, sometimes sleeping during explanations, and this pattern was confirmed in the interview. Despite being conducted online and with a single participant, the PBL lessons motivated her to learn the biodiversity topic because she was interested in the tasks. Her curiosity led her to learn more than expected, helped her retain information, and led her to express a clear preference for learning biology through this method.

"I think learning like this will help me to remember the information for a longer period of time. Also, in exams, we get questions relating to species we know nothing about. So this method will help me to attend these questions too."

This shift in attitude is consistent with research showing that PBL significantly improves student attitudes toward science, problem-solving skills, and views of the learning environment (Ferreira & Trudel, 2012). PBL can therefore help teachers engage students in learning complex topics such as biodiversity.

DISCUSSION

The current action research study examined changes in a Grade 12 student's understanding of biodiversity following participation in PBL. The findings also documented related changes in her performance on higher-order assessment items, metacognitive awareness, transferable skills, and attitude toward learning biology. The discussion considers how features of PBL may have contributed to these observed changes.

The central mechanism is that PBL replaced passive reception of content with active, self-directed construction of knowledge, which is central to inquiry-based learning. Recent evidence shows that PBL and deep-learning approaches significantly improve students' active and independent learning, both directly and through self-regulated learning (Tamami et al., 2025). The open-ended, real-world tasks required the student to locate, evaluate, and integrate information from multiple sources, which forced deeper processing than teacher-delivered notes and explains the depth of understanding she demonstrated (Funa & Prudente, 2021). Because the problems were contextual rather than abstract, the student had to connect biodiversity concepts to real situations, precisely the kind of integration that higher-order questions demand and that her post-assessment performance reflected.

A second mechanism is autonomy and ownership, which are central to inquiry-based learning. Being responsible for her own research shifted the student from a passive recipient to an active agent in her learning. A meta-analysis of PBL across disciplines found a significant effect on self-directed learning compared with lecture-based instruction, with personal autonomy showing the strongest effect (Leary, 2021). This likely explains her motivation and the fact that she read beyond what was assigned. Therefore, when learners direct their own inquiry, they may invest more in both the process and the outcome.

Her metacognitive growth, evidenced by identifying her own misconceptions about mutation and natural selection, follows from the same inquiry process. When learners generate and evaluate their own knowledge, they become aware of gaps in it. This is consistent with quasi-experimental evidence that PBL significantly improves high school students' metacognitive skills alongside their biology concept achievement (Jannah et al., 2025b).

The development of transferable skills (research, digital literacy, and critical thinking) and the positive shift in attitude are also consistent with the inquiry-based learning literature. PBL has been shown to significantly improve student attitudes toward science, problem-solving skills, and positive views of the learning environment (Funa & Prudente, 2021).

LIMITATIONS

The study was conducted with a single student, so the findings are case-specific and cannot be generalized to all students or used to determine how PBL would function with a whole class. Because the study did not include a comparison condition, the observed changes cannot be attributed solely to PBL; they may also reflect repeated assessment, teacher support, or the participant's individual characteristics. The teacher-researcher's dual role and reliance on one participant's self-reported reflections may also have influenced the qualitative findings, despite the use of triangulation, second marking, and second reviewer. In addition, the lessons were delivered online via Google Meet rather than in a physical classroom, and the untimed tasks were completed at the student's convenience. It therefore remains uncertain whether similar activities and outcomes could be achieved with approximately 30 students during a standard 45-minute school period. These constraints mean that the findings should be interpreted as promising, context-specific evidence from one case rather than proof of effectiveness.

ACTION PLAN

- Increase the sample size. Future studies should include a full class (25 to 30 students) rather than one participant, and ideally multiple classes, so findings can be compared across groups and generalization claims become defensible.

- Use multi-site implementation. Conducting the same PBL design across several schools (two or three secondary schools) would show whether the effects hold in different settings and student populations, strengthening the external validity of results.
- Use group tasks. Assigning collaborative group tasks distributes the workload and mirrors real classroom conditions, testing how PBL functions with interdependent learners.
- Provide clear task instructions. Each task should come with detailed instructions and explicit teacher expectations, so students are not confused about the quality of work required.
- Teach information-search skills in advance. Before beginning the tasks, students should learn how to formulate searches, evaluate relevance, and identify sources aligned with the learning outcomes.
- Include recommended sources. Attaching suggested sources to each task guides students toward content aligned with the learning outcomes.
- Time the lessons. Future implementation should follow a fixed schedule to test whether tasks can be completed within the standard lesson period.

IMPLICATIONS

Although the findings cannot be generalized to a mixed-ability class of approximately 30 students, they identify practices worth evaluating in broader classroom settings. Meaningful PBL tasks may support attentiveness and, when combined with collaboration, may contribute to a constructivist learning environment and more positive attitudes toward biology. Similar designs may also be explored in other science subjects, business, and the arts, where authentic problems can help connect disciplinary content to practical contexts. These possibilities require further classroom-based evaluation before claims about effectiveness or transfer across subjects can be made.

CONCLUSION

The study provides an affirmative answer to its research question for the participant: following the PBL intervention, she demonstrated stronger conceptual understanding of biodiversity, improved performance on higher-order assessment items, and a more positive attitude toward biology. These outcomes are consistent with PBL's emphasis on active, self-directed, and context-rich inquiry, which may support conceptual understanding, metacognitive and transferable skills, and motivation. Given the constraints of a single-participant online intervention, the findings support further classroom-based implementation and evaluation of PBL using differentiated and collaborative tasks, larger and more varied samples, and standard lesson timings.

REFERENCES

- Abugri, B. A., Assibi, M. A., Amalba, A., Gaa, P. K., Kpebu, S. E. A., Karikari, P. A. A., & Mogre, V. (2026). The effects of problem-based learning (PBL) on undergraduate medical students' critical thinking and communication skills development: A scoping review across resource-rich and resource-limited settings (2015–2024). *PLOS ONE*, 21(2), e0342599. <https://doi.org/10.1371/journal.pone.0342599>
- Adah Miller, E., Li, T., Chen, I.-C., Krajcik, J., & Codere Kelly, S. (2025). Designing for and investigating elementary students' cognitive flexibility, science, and literacy achievement in project-based science learning. *Disciplinary and Interdisciplinary Science Education Research*, 7(1), 13. <https://doi.org/10.1186/s43031-025-00131-1>
- Akcaay, B., & Benek, İ. (2024). Problem-based learning in Türkiye: A systematic literature review of research in science education. *Education Sciences*, 14(3), 330. <https://doi.org/10.3390/educsci14030330>
- Antonio, R. P., & Prudente, M. S. (2023). Effects of inquiry-based approaches on students' higher-order thinking skills in science: A meta-analysis. *International Journal of Education in Mathematics, Science and Technology*, 12(1), 251–281. <https://doi.org/10.46328/ijemst.3216>
- Purba, A., Abidina, K. A., Azzahra, M. Y., Nuraini, A., Nuraini, C., Latifui, N., Naibaho, E. R., Ristanto, R. H., & Suryanda, A. (2026). Analysis of learners' misconceptions on biodiversity using the BIODIV-MDT instrument. *BioEdu: Berkala Ilmiah Pendidikan Biologi*, 15(1). <https://ejournal.unesa.ac.id/index.php/bioedu>
- Byrne, D. (2022). A worked example of Braun and Clarke's approach to reflexive thematic analysis. *Quality & Quantity*, 56(3), 1391–1412. <https://doi.org/10.1007/s11135-021-01182-y>
- Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: Complex or simple? Research case examples. *Journal of Research in Nursing*, 25(8), 652–661. <https://doi.org/10.1177/1744987120927206>
- Damanik, J., Nabilla, N., & Sani, R. A. (2024). Exploring student learning outcomes in physics learning using a problem-based learning model with a differentiated learning approach. *JPPI (Jurnal Penelitian Pendidikan Indonesia)*, 10(2), 769. <https://doi.org/10.29210/020243846>
- Eklund, M., & Isotalus, P. (2024). Having it both ways: Learning communication skills in face-to-face and online environments. *Frontiers in Education*, 9, 1270164. <https://doi.org/10.3389/feduc.2024.1270164>

- Ferreira, M. M., & Trudel, A. R. (2012). The Impact of Problem-Based Learning (PBL) on Student Attitudes Toward Science, Problem-Solving Skills, and Sense of Community in the Classroom. *JSTOR*, 47(1), 23–30. <https://www.jstor.org/stable/43858871>
- Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American Psychologist*, 34(10), 906–911. <https://doi.org/10.1037/0003-066X.34.10.906>
- Fox, C. H. (2010). Education and training. *Journal of the American Dental Association*, 141(6), 621–622. <https://doi.org/10.14219/jada.archive.2010.0235>
- Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School Engagement: Potential of the Concept, State of the Evidence. In *Source: Review of Educational Research* (Vol. 74, Number 1). <https://www.jstor.org/stable/3516061>
- Fullick, A., & Sochacki, F. (2018). *Pearson Edexcel International AS/A Level Biology*. Pearson Education Limited.
- Funa, A. A., & Prudente, M. S. (2021). Effectiveness of problem-based learning on secondary students' achievement in science: A meta-analysis. *International Journal of Instruction*, 14(4), 69–84. <https://doi.org/10.29333/iji.2021.1445a>
- Harleni, H., Ganefri, G., Yulastri, A., Giatman, M., Irfan, D., & Effendi, H. (2025). Unveiling the impact of inquiry-based learning: A meta-analysis of student learning outcomes. *AL-ISHLAH: Jurnal Pendidikan*, 17(3). <https://doi.org/10.35445/alishlah.v17i3.7061>
- Hill, A. M., & Smith, H. A. (2005). Research in purpose and value for the study of technology in secondary schools: A theory of authentic learning. *International Journal of Technology and Design Education*, 15, 19–32. <https://doi.org/10.1007/s10798-004-6195-2>
- Honra, J. R., & Monterola, S. L. C. (2026). Enhancing biology students' cognitive flexibility through problem-based learning moderated by transdisciplinary thinking. *The Journal of Educational Research*, 119(1), 129–139. <https://doi.org/10.1080/00220671.2025.2525245>
- Husna, H., Nerita, S., & Safitri, E. (2023). Analysis of student difficulties in learning biology. *Journal of Biology Education Research*. <https://journal.unpak.ac.id/index.php/jber>
- Ilhamdi, M. L., Rahmani, A. V., & Syazali, M. (2022). Analysis of misconceptions of senior high school students on biodiversity materials, interactions, and their role in nature. *Jurnal Pijar Mipa*, 17(6), 764–769. <https://doi.org/10.29303/jpm.v17i6.3436>

- Ivaningtias, Y., Indana, S., & Indah, N. K. (2024). Validity of problem-based learning biodiversity e-book integrating Ruwat Petirtaan Jolutundo's local wisdom for science literacy. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 10(3), 874–886. <https://doi.org/10.22219/jpbi.v10i3.36690>
- Iwan, I., Jeni, J., & Nurfathurrahmah, N. (2025). Biodiversity module based on problem-based learning local wisdom assisted by augmented reality: Improving students' critical thinking. *Jurnal Eduscience*, 12(2), 497–510. <https://doi.org/10.36987/jes.v12i2.6925>
- Jannah, M., Suratno, & Siswati, B. H. (2025). The effect of problem-based learning integrated with collaborative learning on metacognitive skills and biology concepts. *International Journal of Research and Review*, 12(5), 191–198. <https://doi.org/10.52403/ijrr.20250523>
- Johnson, J. L., Adkins, D., & Chauvin, S. (2020). A review of the quality indicators of rigor in qualitative research. *American Journal of Pharmaceutical Education*, 84(1), 7120. <https://doi.org/10.5688/ajpe7120>
- Kakar, Z. U. H., Rasheed, R., Rashid, A., & Akhter, S. (2023). Criteria for assessing and ensuring the trustworthiness in qualitative research. *International Journal of Business Reflections*, 4(2), 150–173. <https://doi.org/10.56249/ijbr.03.01.44>
- Kallio, H., Pietilä, A.-M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, 72(12), 2954–2965. <https://doi.org/10.1111/jan.13031>
- Kaminske, A. N., Kuepper-Tetzel, C. E., Nebel, C. L., Sumeracki, M. A., & Ryan, S. P. (2020). Transfer: A review for biology and the life sciences. *CBE—Life Sciences Education*, 19(3), 1–11. <https://doi.org/10.1187/cbe.19-11-0227>
- Kassab, S. E., El-Baz, A., Hassan, N., Hamdy, H., Mamede, S., & Schmidt, H. G. (2023). Construct validity of a questionnaire for measuring student engagement in problem-based learning tutorials. *BMC Medical Education*, 23(1), 844. <https://doi.org/10.1186/s12909-023-04820-1>
- Leary, H. M. (2021). *Self-directed learning in problem-based learning versus traditional lecture-based learning: A meta-analysis* [Doctoral dissertation, Utah State University]. DigitalCommons@USU. <https://digitalcommons.usu.edu/etd/1173>
- Liu, Y., & Pásztor, A. (2022). Effects of problem-based learning instructional intervention on critical thinking in higher education: A meta-analysis. *Thinking Skills and Creativity*, 45, 101069. <https://doi.org/10.1016/j.tsc.2022.101069>

- Lu, L., Mustakim, S. S., & Muhamad, M. M. (2025). A meta-analysis of the effectiveness of problem-based learning on critical thinking. *European Journal of Educational Research*, 14(3), 789–804. <https://doi.org/10.12973/eu-jer.14.3.789>
- Manuaba, I. B. A. P., No, Y., & Wu, C.-C. (2022). The effectiveness of problem-based learning in improving critical thinking, problem-solving, and self-directed learning in first-year medical students: A meta-analysis. *PLOS ONE*, 17(11), e0277339. <https://doi.org/10.1371/journal.pone.0277339>
- Marthaliakirana, A. D., Suwono, H., Saefi, M., & Gofur, A. (2022). Problem-based learning with metacognitive prompts for enhancing argumentation and critical thinking of secondary school students. *Eurasia Journal of Mathematics, Science and Technology Education*, 18(9), em2148. <https://doi.org/10.29333/ejmste/12304>
- McDaniel, M. A., Cahill, M. J., Frey, R. F., Limeri, L. B., & Lemons, P. P. (2022). Learning introductory biology: Students' concept-building approaches predict transfer on biology exams. *CBE—Life Sciences Education*, 21(4), ar66. <https://doi.org/10.1187/cbe.21-12-0335>
- Mertler, C. A. (2017). *Action research: Improving schools and empowering educators*. SAGE Publications.
- Ministry of Education. (2017). *School statistics 2017*. https://education.gov.mv/storage/files/statistics/STAT_BOOK_2017.pdf
- Morris, D. L. (2025). Rethinking science education practices: Shifting from investigation-centric to comprehensive inquiry-based instruction. *Education Sciences*, 15(1), 73. <https://doi.org/10.3390/educsci15010073>
- Moskal, B. M. (2002). Recommendations for developing classroom performance assessments and scoring rubrics. *Practical Assessment, Research, and Evaluation*, 8(1), Article 14. <https://doi.org/10.7275/jz85-rj16>
- Naeem, M., Ozuem, W., Howell, K., & Ranfagni, S. (2023). A step-by-step process of thematic analysis to develop a conceptual model in qualitative research. *International Journal of Qualitative Methods*, 22. <https://doi.org/10.1177/16094069231205789>
- Nicholus, G., Muwonge, C. M., & Joseph, N. (2023). The role of problem-based learning approach in teaching and learning physics: A systematic literature review. *F1000Research*, 12, 951. <https://doi.org/10.12688/f1000research.136339.1>
- National Institute of Education. (2014). *Pedagogy and assessment guide*. <https://ied.gov.mv/storage/uploads/brY4MlqB/aqendnha.pdf>

- Nigussie, K. T., Semahagn, B. K., Mersha, B. S., & Tamiru, A. B. (2025). Effects of paper-based problem scenarios on high school biological problem-solving skills and academic achievement. *Disciplinary and Interdisciplinary Science Education Research*, 7(1), 21. <https://doi.org/10.1186/s43031-025-00138-8>
- Nurhasanah, M., Suprpto, P. K., & Ardiansyah, R. (2024). The effectiveness of problem-based learning assisted by Articulate Storyline interactive media on students' critical-thinking skills. *Jurnal Inovasi Pendidikan IPA*, 10(1), 1–9. <https://doi.org/10.21831/jipi.v10i1.64847>
- Nwankwo, A. L., Ugwu, T. U., Ukala, G., & Benson, O. O. (2024). The effect of hands-on activity and problem-based learning on achievement of biology students in Enugu State. *Inornatus: Biology Education Journal*, 4(1), 46–56. <https://doi.org/10.30862/inornatus.v4i1.574>
- Overton, T. L., & Randles, C. A. (2015). Beyond problem-based learning: Using dynamic PBL in chemistry. *Chemistry Education Research and Practice*, 16, 251–259. <https://doi.org/10.1039/C4RP00248B>
- Pearson Education Limited. (2020). *International advanced level biology specification*.
- Ram, P., Ram, A., & Sprague, C. (2005, June). *From student learner to professional learner: Training for lifelong learning through online PBL* [Conference paper]. International Conference on Problem-Based Learning, Lahti, Finland. <https://sites.cc.gatech.edu/fac/ashwin/papers/er-05-03.pdf>
- Richardson, V. (2003). Constructivist pedagogy. *Teachers College Record*, 105(9), 1623–1640. <https://doi.org/10.1046/j.1467-9620.2003.00303.x>
- Rubrica, R. D. B. (2019). An action research on project-based learning and understanding by design and their effects on the science achievement and attitude of science students. *Journal of Education and Practice*, 10(5). <https://doi.org/10.7176/JEP/10-5-02>
- Sagor, R. (2000). Guiding school improvement with action research. Association for Supervision and Curriculum Development.
- Sanders, J. (2009). Single-case research: An underused approach for medical educational research. *Education for Primary Care*, 20(1), 8–9. <https://doi.org/10.1080/14739879.2009.11493756>
- Smith, K., Maynard, N., Berry, A., Stephenson, T., Spiteri, T., Corrigan, D., Mansfield, J., Ellerton, P., & Smith, T. (2022). Principles of problem-based learning (PBL) in STEM education: Using expert wisdom and research to frame educational practice. *Education Sciences*, 12(10), 728. <https://doi.org/10.3390/educsci12100728>

- Suryati, S., Adnyana, P. B., Ariawan, I. P., & Wesnawa, I. G. A. (2024). Integrating constructivist and inquiry-based learning in chemistry education: A systematic review. *Hydrogen: Jurnal Kependidikan Kimia*, 12(5), 1166. <https://doi.org/10.33394/hjkk.v12i5.13571>
- Tamami, F. Q. A., Shohib, M. W., Maksum, M. N. R., Rabbi, M. F., Daud, Z., Fadli, N., & Wadi, M. F. (2025). The effect of deep learning and problem-based learning on active and independent learning with a mediating variable. *Journal of Research in Instructional*, 5(2), 613–628. <https://doi.org/10.30862/jri.v5i2.718>
- Trullàs, J. C., Blay, C., Sarri, E., & Pujol, R. (2022). Effectiveness of problem-based learning methodology in undergraduate medical education: A scoping review. *BMC Medical Education*, 22(1), 104. <https://doi.org/10.1186/s12909-022-03154-8>
- Tshering, S., & Yangden, P. (2021). Effects of inquiry-based learning approach on learning achievement and learning satisfaction among Grade Four students toward science. *Asian Journal of Education and Social Studies*, 18(2), 25–32. <https://doi.org/10.9734/ajess/2021/v18i230438>
- Uliyandari, M., Candrawati, E., Herawati, A. A., & Latipah, N. (2021). Problem-based learning to improve concept understanding and critical-thinking ability of science education undergraduate students. *IJORER: International Journal of Recent Educational Research*, 2(1), 65–72. <https://doi.org/10.46245/ijorer.v2i1.56>
- Uluçınar, U. (2023). The effect of problem-based learning in science education on academic achievement: A meta-analytical study. *Science Education International*, 34(2), 72–85. <https://doi.org/10.33828/sei.v34.i2.1>
- Usman, G. B. T., Mohd Norawi Ali, & Mohammad Zohir Ahmad. (2023). Effectiveness of STEM problem-based learning on the achievement of biology among secondary school students in Nigeria. *Journal of Turkish Science Education*, 20(3), 453–467. <https://doi.org/10.36681/tused.2023.026>
- Vincent R, G., & Lyons, R. (2015). *Problem-Based Learning: Six Steps to Design, Implement, and Assess*. <https://www.facultyfocus.com/articles/course-design-ideas/problem-based-learning-six-steps-to-design-implement-and-assess/>
- Wang, X.-M., Hu, Q.-N., Hwang, G.-J., & Yu, X.-H. (2023). Learning with digital technology-facilitated empathy: an augmented reality approach to enhancing students' flow experience, motivation, and achievement in a biology program. *Interactive Learning Environments*, 31(10), 6988–7004. <https://doi.org/10.1080/10494820.2022.2057549>