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Evaluation of biology practicum implementation: Analysis of achievement of science process skills, literacy numeracy and conceptual understanding

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Abstract

Science process skills (SPS) are fundamental for 21st-century education, as they foster students' reasoning, inquiry competence, and conceptual understanding. In biology learning, SPS play a central role in cultivating scientific literacy and preparing students with critical thinking and problem-solving abilities required in the global era. Yet, international assessments such as PISA consistently show that Indonesian students perform below the OECD average in scientific literacy, indicating weaknesses in evidence-based reasoning and application of scientific concepts. This problem is often linked to teacher-centered instruction and limited implementation of inquiry-based laboratory activities in schools. This study investigates the implementation of SPS in biology practicum through interviews with teachers and analysis of laboratory activity documents from five public senior high schools in Makassar. A qualitative descriptive method was applied, focusing on indicators such as observation, classification, prediction, data interpretation, hypothesis formulation, experimental planning, communication, and concept application. The results reveal that observation and interpretation are partially practiced but lack structured guidance and do not encourage student autonomy. Other skills, including classification, prediction, hypothesis formulation, experimental planning, and communication, are rarely emphasized because students mostly follow predetermined procedures. The findings conclude that biology practicum has not effectively supported SPS development, reinforcing students' low scientific literacy. Strengthening inquiry-based learning and enhancing teacher professional development are recommended to improve laboratory pedagogy and foster meaningful, student-centered science learning.

Abstrak. *Keterampilan proses sains (KPS) merupakan aspek fundamental dalam pendidikan abad ke-21 karena berperan penting dalam menumbuhkan penalaran, kompetensi inkuiri, dan pemahaman konsep peserta didik. Dalam pembelajaran biologi, KPS menjadi kunci untuk mengembangkan literasi sains sekaligus mempersiapkan siswa dengan kemampuan berpikir kritis dan pemecahan masalah yang dibutuhkan pada era global. Namun, asesmen internasional PISA secara konsisten menunjukkan bahwa capaian literasi sains siswa Indonesia berada di bawah rata-rata OECD, yang mencerminkan kelemahan dalam penalaran berbasis bukti dan penerapan konsep ilmiah. Kondisi ini sering dikaitkan dengan pembelajaran berpusat pada guru serta keterbatasan penerapan praktikum berbasis inkuiri di sekolah. Penelitian ini bertujuan untuk mengeksplorasi implementasi KPS dalam kegiatan praktikum biologi melalui analisis wawancara dengan guru biologi dan dokumen kegiatan laboratorium (DKL) di lima sekolah menengah atas negeri di Makassar. Penelitian menggunakan metode deskriptif kualitatif dengan fokus pada kelengkapan dan kedalaman indikator KPS, seperti mengamati, mengklasifikasi, memprediksi, menafsirkan data, merumuskan hipotesis, merancang eksperimen, mengomunikasikan, dan menerapkan konsep. Hasil menunjukkan bahwa keterampilan mengamati dan menafsirkan sudah diterapkan namun belum terstruktur dan kurang mendorong kemandirian siswa. Sementara itu, keterampilan lain seperti klasifikasi, prediksi, dan perumusan hipotesis masih jarang dilatihkan. Perencanaan eksperimen dan komunikasi ilmiah juga terbatas karena siswa hanya mengikuti prosedur yang tersedia. Disimpulkan bahwa pendekatan praktikum saat ini belum mendukung pengembangan KPS secara menyeluruh. Diperlukan penerapan model pembelajaran berbasis inkuiri serta pelatihan profesional guru untuk meningkatkan pedagogi laboratorium dan pembelajaran yang berorientasi pada siswa.*

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A. Introduction

Biology education plays a crucial role in developing 21st-century competencies, particularly in enhancing students' scientific literacy, conceptual understanding, and critical thinking skills (Yacoubian, 2024). The instructional approach in biology, as a branch of science education, requires a strategy that not only delivers content but also fosters students' deep understanding and scientific problem-solving skills (Nurhayati et al., 2022). Practicum activities have been recognized as an effective learning strategy to achieve these goals through direct student engagement in scientific processes. Student involvement in practical activities allows the development of science process skills (SPS) in a contextual and meaningful way (Rahmah et al., 2021). An inquiry-based framework within practicum enables learners to engage in the complete scientific processfrom observation and hypothesis formulation to experimentation, data analysis, and drawing evidence-based conclusions (Putri et al., 2022).

The implementation of biology practicums in Indonesian schools remains largely dominated by a verification model that emphasizes procedural learning (Sypsas et al., 2020). This model limits students' cognitive engagement and fails to support the development of scientific reasoning (Nunaki et al., 2021). Several studies have identified major obstacles in effective practicum implementation, such as insufficient laboratory facilities, limited instructional time, and the lack of teacher competence in designing inquiry-based learning experiences (Karamustafaoğlu, 2011). These constraints hinder the mastery of SPS and result in shallow conceptual understanding that relies on memorization rather than critical thinking (Trisianawati & Darmawan, 2017).

Numeracy skills**,** which are an integral part of scientific literacy, remain insufficiently integrated into biology practicum activities (Geiger et al., 2015; Nuristiqomah, 2023). These skills are essential in biology, for instance in interpreting graphs, calculating biological rates, and analyzing experimental data (Nuraeni et al., 2019). Student worksheets can ideally serve as instructional tools that strengthen numeracy abilities (Cartwright et al., 2020). Most existing worksheets**,** however, still focus on procedural steps without guiding students to critically analyze numerical data or engage in quantitative reasoning (OECD, 2019). National and international assessments, such as PISA, consistently indicate that Indonesian students' numeracy performance is below the international average (Fenanlampir et al., 2019). This deficiency not only impairs students' ability to engage in data-driven thinking but also reduces their capacity to construct scientific arguments based on valid evidence (Fauzi & Fadilah, 2024).

A preliminary study conducted in five public senior high schools in Makassar revealed that biology practicum activities were still predominantly procedural in nature. Students were generally asked to follow fixed steps and answer factual or descriptive questions, without opportunities to design experiments or analyze quantitative data. Teachers also reported the lack of laboratory tools and worksheets that integrate SPS with numeracy-based tasks. These observations are consistent with previous international studies indicating that practical work in science classrooms often becomes a routine exercise rather than an inquiry-driven experience (Lunetta et al., 2024). Such practices limit students' engagement in scientific reasoning, critical thinking, and evidence-based argumentation (Abrahams & Millar, 2008). Therefore, there is an urgent need to develop practicum resources that contextualize SPS and numeracy within meaningful inquiry-based activities.

The development of inquiry-based worksheets that integrate numeracy literacy offers a strategic and timely solution to these challenges (Ulus & Oner, 2020; Kang, 2022; Maftuhah, 2024). The use of such worksheets enriches students' scientific learning experience and encourages logical reasoning, data interpretation, and evidence-based scientific communication (Dewi et al., 2023; Phillips, 2023). Inquiry-based worksheets can also function as authentic assessment instruments that simultaneously evaluate students' SPS and numeracy skills (Anbiya et al., 2023). Previous studies have tended to focus separately on SPS or numeracy skill development. This study seeks to bridge that gap by examining how biology practicum implementation in schools supports the integrated development of SPS, numeracy literacy, and conceptual understanding.

This research reinforces previous findings on the effectiveness of inquiry-based learning, while also offering a corrective perspective by highlighting the often-neglected aspect of numeracy integration. The findings of this study are expected to provide a foundation for designing relevant, contextual, and applicable practicum tools that support meaningful and transformative biology learning.

B. Material and method

This study employed a descriptive qualitative research design aimed at providing a comprehensive understanding of the implementation of biology practicum in senior high schools. The focus was on examining its impact on students' SPS, numeracy literacy, and conceptual understanding, particularly in the teaching of cellular respiration. This design was considered appropriate as it allowed for an in-depth exploration of real classroom practices and teacher perspectives in a natural context.

The population in this study consisted of biology teachers in public senior high schools across Makassar City. The sample was selected purposively based on the following inclusion criteria: (1) actively teaching biology at the grade XI level, (2) having implemented practicum activities in the topic of cellular respiration, and (3) being willing to participate in the study. Five biology teachers who met these criteria were included in the final sample. This purposive sampling ensured the involvement of teachers with relevant experience in both practicum implementation and inquiry-based approaches.

The instruments used in this study consisted of semi-structured interview guidelines and a worksheet analysis framework. The interview guidelines were designed to explore teachers' experiences in planning and implementing practicum activities, particularly the challenges they faced when applying inquiry-based approaches. The questions were developed with reference to indicators of SPS and numeracy competencies to ensure that the data collected would reflect the targeted aspects of learning. In addition, the worksheet analysis framework was developed based on Novak and Gowin's (1984) theory, focusing on key components such as the formulation of essential questions, integration of relevant scientific concepts, organization and processing of data, and formulation of evidence-based conclusions. Both instruments underwent expert validation prior to use to guarantee their clarity, relevance, and accuracy in addressing the research objectives.

The procedures of this study were conducted systematically, beginning with the preparation stage, which included the development of the interview guidelines and the worksheet analysis framework, followed by expert validation to ensure their suitability for data collection. Once validated, data collection was carried out through in-depth interviews with biology teachers who met the sampling criteria. The interviews were conducted face-to-face, recorded to maintain data accuracy, and later transcribed for analysis. Simultaneously, student worksheets used in the teaching of cellular respiration were collected from the participating schools to be examined through document analysis. The next stage involved data management, where interview transcripts were organized and coded, while worksheets were categorized according to the analysis framework. Subsequently, data were analyzed using thematic analysis for the interview results and Novak and Gowin's framework for the worksheets, allowing for the identification of recurring themes and the evaluation of worksheet quality. To strengthen the validity of the findings, triangulation was performed by comparing and integrating the results obtained from the interviews and worksheet analysis, thereby providing a more comprehensive understanding of practicum implementation in the classroom.

Interview data were analyzed using thematic analysis, which involved coding, categorizing, and synthesizing responses into broader themes such as the frequency of practicum activities, variety of laboratory experiences, and challenges in inquiry-based learning. Document analysis of worksheets was carried out using Novak and Gowin's (1984) framework, focusing on how well the worksheets facilitated problem formulation, data interpretation, and conclusion-making. Finally, triangulation between interview and worksheet analysis results was employed to strengthen the credibility and trustworthiness of the findings.

C. Results and discussion

Implementation of learning biology

The implementation of practicum-based biology instruction in Indonesia remains constrained by multiple systemic challenges that limit its potential to improve students' conceptual understanding (Lunetta et al., 2010). Practicum activities, which ideally serve to reinforce theoretical knowledge through direct scientific investigation, are often marginalized in actual classroom practices (Adams-Wiggins & Dancis, 2023). Based on interviews conducted in five public high schools in Makassar, it was found that biology practicum was implemented only twice per semester in three schools, while two others did not conduct any practicum at all. A primary reason cited was the conversion of biology laboratories into classrooms due to space shortages and insufficient time allocation factors also emphasized by Rahmah et al. (2021) who noted that the lack of tools, limited material availability, and time constraints hinder laboratory-based learning.

The limited integration of practicum activities is further exacerbated by the predominant use of lecture-based teaching methods, which reduces practical work to a secondary or optional component of instruction (Shana et al., 2024). Schools that attempt to modernize learning through project-based or technology driven strategies still fail to replicate the distinct cognitive benefits that students gain from engaging in experimental investigations (Zhang, et al., 2024). Consequently, students' scientific reasoning and inquiry abilities remain underdeveloped due to insufficient exposure to authentic scientific practices. Learning becomes passive and less engaging, resulting in low motivation and limited participation (Nugroho et al., 2023; Çetin et al., 2024).

Teacher readiness is another critical factor. Interviews reveal that many biology teachers lack the competence to design and facilitate inquiry-based laboratory activities (Daniah, 2022; Delgado-Iglesias et al., 2024). The Learner Worksheets used in these practicums primarily emphasize procedural steps, without challenging students to think critically or apply numeracy skills when interpreting experimental data. This is problematic, as well-

designed worksheets should incorporate observable phenomena that stimulate students' scientific reasoning (Zidan & Supriatno, 2023). The misalignment between the pedagogical potential of practicum and its current execution deprives students of meaningful, explorative learning experiences that could foster deeper biological understanding (Diem et al., 2024).

Addressing these gaps requires systemic intervention, including equipping schools with adequate laboratory tools and designing practicum strategies that develop students' basic SPS. Moreover, sustained professional development is essential to prepare teachers in crafting inquiry-based experiments. Integrating numeracy elements within student worksheets will also help ensure that biology learning is not only conceptually rich but also grounded in data analysis and scientific reasoning (Sholihan et al., 2017).

Science process skills achievement

Science process skills reflect how students think and act scientifically in learning activities, especially in practicum activities. Based on the results of interviews with biology teachers and a review of student worksheet documents on respiration material in five senior high school in Makassar, it was found that the application of these skills was still uneven and tended not to run optimally in most indicators. The results of the analysis of the achievement of SPS can be seen in Table 1.

Table 1 Results analysis of SPS achievement

Indicator	Finding	Achievement
Observation	Students make observations, but they are unstructured	Implemented, but not systematic yet
Interpretation	Students wait for the teacher's direction, have not analyzed the data themselves	Not yet implemented independently
Classification	Not practiced in practicum, variables are not grouped	Not yet optimal
Prediction	Did not start with making conjectures before practicum	Not yet optimal
Communication	Only report writing, no discussion or presentation	Undeveloped
Hypothesis	No practice in making scientific conjectures before the experiment	Not yet implemented
Planning the experiment	Students only follow the procedure from the teacher without designing their own	Not yet optimal
Apply concepts or principles	Application of concepts has not appeared in the analysis of practicum results	Not yet optimal
Asking questions	Students rarely raise questions during the practicum	Undeveloped

The results of interviews and analysis of student worksheet show that although students have made observations during the practicum, the process has not been directed in a structured and systematic manner. The teacher said that the Student Worksheet used has not provided clear instructions on how to record the results of observations sequentially. As a result, students' observations tend to be untidy, incomplete, and not easily used as a basis for further analysis. This finding is consistent with Wahyuni et al. (2020) who emphasized that systematic observation guides are important to help students form scientific thinking patterns gradually and continuously. In addition, the interpretation of practicum data has not been carried out independently. The analysis process is still dominated by the teacher, so students have not been given the space to draw their own meaning from the practicum results they observe.

The aspects of classification, prediction, and hypothesis, it appears that these skills have not been optimally integrated into practicum activities. The interviews revealed that students were not directed to classify data or make initial guesses before the experiment was conducted. The practicum steps are carried out directly without any exploration or initial discussion phase, so that the development of students' scientific thinking skills becomes less honed. In fact, according to Ioannidou and Erduran (2021), the ability to make predictions and formulate hypotheses is very important in fostering a reflective and logical mindset. The non-implementation of hypotheses as part of students' scientific cycle also shows the lack of habituation to the scientific thinking process. This is in line with the results of research by Gizaw & Sota (2023) which states that the dominance of the instructional approach and the lack of exploratory activities are inhibiting factors in the development of SPS.

The skills of designing experiments and scientific communication are also still not optimally developed. Practicum documents show that all experimental procedures have been determined by the teacher, so students only follow the steps available without the opportunity to design their own. Communication activities are still limited to written reports, with no room to present or discuss findings openly in class. In fact, according to Hasnunidah et al. (2020), scientific discussions and presentations are an important part of shaping argumentation and critical thinking skills. This lack of communication activities shows that students are not accustomed to conveying ideas or being accountable for the results

of their experiments. To overcome this, the learning approach needs to shift towards a more active and explorative direction. As emphasized by Li et al. (2024), the consistent application of inquiry-based learning can encourage students to think independently, formulate hypotheses, and be actively involved in the scientific decision-making process during practicum.

Numeracy literacy skills achievement

Numeracy literacy in practicum is evaluated based on the extent to which students are able to interpret experimental data and use it in problem solving. The results of the numeracy literacy skill achievement analysis can be seen in Table 2.

The numeracy literacy skills of students in the context of biology practicum still show less than optimal results. Based on interviews with biology teachers in five high schools, it is known that students' numeracy skills in practicum implementation are low. Numerical activities such as calculating the respiration rate based on the volume of gas produced against time have not been an explicitly integrated part of the Learner Worksheet. Generally, students only record the final results of the practicum without a quantitative analysis process or comparison between treatments. This shows that numeracy skills have not been a focus in learning biology practicum. In fact, these skills are very important in building a complete scientific understanding. Numeracy literacy is the foundation for data-based decision making and systematic interpretation of experimental results (Mullis et al., 2020). In addition, the lack of integration of numeracy activities in practicum also reflects the weak application of contextual learning approaches that should be able to connect mathematical concepts with biological phenomena concretely.

Table 2 Results of the analysis of achievement of numeracy literacy skills

Indicator	Finding	Achievements
Calculate	Calculating done in student worksheets and practicum implementation	Low
Retrieve/obtain	Students are able to read the data, but are less careful about units and scales	Moderate
State/make a model	Not used to making mathematical models or graphs of relationships between variables	Low
Interpret	Students have difficulty reading trend charts	Moderate
Making justification	Arguments have not been supported by numerical data; dominantly based on memorization.	Low
Summarize	Conclusions do not explicitly reflect numerical evidence	Moderate

Students' numeracy literacy limitations are also evident in the scientific reasoning aspect. The teacher said that most students were not accustomed to building simple mathematical models, such as constructing respiration rate equations or drawing graphs of the relationship between experimental variables, such as temperature and respiration yield. Students tend to view numerical data only as stand-alone numbers, not as a means to find meaningful patterns or trends. For example, in the practicum on the effect of temperature on respiration, students have difficulty in relating temperature variations to respiration rate which should be visualized in the form of a graph. The ability to interpret graphs is an integral part of numeracy literacy in STEM (Science, Technology, Engineering, and Mathematics) learning. Visual representations such as graphs and tables play an important role in helping students understand the connections between concepts and strengthen mastery of biological content (National Research Council, 2012). Therefore, it is very important for teachers and developers of student worksheet to guide students in building understanding through representative models and data visualization.

The application aspect of numeracy skills shows that students are still not accustomed to compiling scientific arguments based on numerical data. Based on interviews, teachers stated that in the process of discussion and writing practicum reports, students often conclude results based on memorization or general logic, not on the basis of empirical evidence obtained during practicum. Data-based scientific justification is still a weak skill, although it is very important in bridging between observations and biological concepts learned. Widodo et al. (2023) emphasized that numeracy-based learning in science can improve students' critical and argumentative thinking skills. Therefore, the student worksheet needs to be explicitly designed to train students to draw conclusions based on numerical data and provide strong scientific justification. This habit will form a more accurate and reflective pattern of scientific thinking in biology experiments at school.

Analysis of knowledge construction

The analysis of the knowledge construction aspect aims to study the process of knowledge construction, which is ideally formed based on objects or phenomena that appear, recorded, and used to construct knowledge (Zahra et al., 2021.) The analysis was carried out by paying attention to the meeting between what was known and what had been done according to the Vee diagram. The results of the assessment and interpretation in this aspect are described in Table 3.

Table 3 Knowledge analysis results

Parameters	Student worksheet					SD (%)
	1	2	3	4	5	
Focus questions	1	1	0	0	0	13,33
Object/event	2	2	1	1	1	46,67
Theory/principal/ concept	2	1	1	1	1	40
Record/transformation	2	2	1	1	2	53,33
Knowledge claim	2	2	1	0	1	40

Based on Table 3, the results of the analysis of knowledge construction, the focus question indicator shows that there are two student worksheets that display focus questions and three student worksheets that are identified as having focus questions but do not support observations of objects and do not guide in the acquisition of concepts, showing a result of 13.33%. The object or event of this practicum is the measurement of the amount of oxygen inhaled by insects. Objects can be identified but some are not in accordance with the focus of the question. can be identified and in accordance with the focus of the question, or events and objects can be identified but not in accordance with the focus of the question so that it shows a result of 46.67%. The concept indicator with a percentage of 40% shows that there are. There are 3 student worksheets that have concepts and more or less one principle (methodological conceptual) or relevant concepts and theories can be identified so that it shows a result of 46.67%. There are student worksheets that have concepts that can be identified but without principles. Written principles are knowledge gained from laboratory activities.

There are three student worksheets that recording activity can be identified, but it is not consistent with the main question or main activity. There are two student worksheets that can be identified and there are questions and in accordance with the focus question. For the Knowledge Claim indicator, it has a percentage of 40%. Knowledge claims are analyzed from the presence of directions to conclude or from leading questions. There are still student worksheets that do not have knowledge claims. There is 1 student worksheet that is not related to concepts and principles and there are 2 student worksheets that are related to concepts that can be used to generalize but are not consistent with data recording and transformation. Based on the overall knowledge construction analysis, the student's worksheet analysis is still lacking in constructing student knowledge. The construction of knowledge obtained from practicum implementation is limited because students only learn about breathing such as gas exchange. Students need to learn the concept of respiration more deeply. Students need to know the bioprocesses in respiration. In addition, the practicum only focuses on animals. Whereas the concept of respiration can also be applied to plants. The use of plants in respiration practicum will make it easier for students to carry out the practicum. Therefore, it is necessary to reconstruct student worksheet to be able to construct deeper knowledge. Some studies show that students will be more successful in reconstructing knowledge through involvement in practical activities or laboratory activities either in the classroom or in the biology laboratory (Supriatno, 2018; Ajayi & Ogbeba, 2017).

D. Conclusion

This research found that the implementation of biology practicum in five public schools in Makassar City has not fully supported the development of students' SPS and numeracy literacy, as practical activities remain procedural and teacher-centered. Key scientific indicators such as questioning, classification, prediction, hypothesis formulation, and experimental design are insufficiently developed, while students rarely interpret data independently or engage in scientific communication. These findings highlight the urgent need to develop inquiry-based practicum tools that facilitate student-led exploration, problem formulation, and scientific reasoning. The conceptual contribution of this study lies in providing empirical support for designing practicum activities that foster active scientific engagement, thereby enhancing students' critical thinking, scientific process skills, and understanding of biological concepts.

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