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Development of a Scientific Student Worksheet (LKPD) Based on the OLabs Virtual Laboratory to Improve High School Students' Conceptual Understanding of Osmosis

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Abstract

The urgency of this research lies in the need for an interactive OLabs-based scientific student worksheet to facilitate students' conceptual understanding of osmosis through virtual laboratory activities. Biology learning in schools continues to face limitations in laboratory facilities and suboptimal laboratory utilization, which can hinder students' conceptual understanding. Osmosis is one of the abstract biology topics that requires in-depth understanding. Therefore, learning materials that integrate virtual and real laboratory activities are needed to support the development of accurate conceptual representations. This study developed a scientific Student Worksheet (LKPD) based on the OLabs virtual laboratory to facilitate students' conceptual understanding of osmosis and to examine its validity, practicality, and effectiveness. The LKPD was designed according to the scientific approach stages of observing, questioning, experimenting, associating, and communicating. The study employed a Research and Development (R&D) method using the 4D development model: define, design, develop, and disseminate. The population consisted of Grade XI senior high school students, and a sample of 36 students was selected using purposive sampling. Data were collected through validation sheets, response questionnaires, observations, and tests, and were analyzed quantitatively and descriptively using percentages derived from Guttman- and Likert-scale scoring as well as N-Gain analysis. The results showed that the LKPD achieved a validity score of 93.13% (highly valid), a student-response practicality score of 93.13% (highly practical), and a learning-implementation score of 95.14% (highly practical). The effectiveness test yielded an N-Gain score of 0.88, which was classified as high. Thus, the developed scientific LKPD is feasible for use in osmosis learning to support students' conceptual understanding and can serve as an alternative learning material that integrates a virtual laboratory.

Keywords: *Scientific Student Worksheet (LKPD), Olabs Virtual Laboratory, Osmosis, Conceptual Understanding, Development.*

Introduction

Science education in the 21st century no longer emphasizes memorization, but rather the ability to understand and apply scientific concepts in real-life contexts. This expectation has not yet been fully reflected in the 2022 PISA results, which indicate that Indonesian students' scientific literacy remains relatively low. The previous studied reported that the average science performance of Indonesian 15-year-old students was 383 points, far below the OECD average of 485 points (OECD, 2023). The proportion of low-performing students in science who scored below Level 2 was 65.8%, compared with an OECD average of only 24.5%. Meanwhile, 0.0% of Indonesian students reached Levels 5 or 6 in science, compared with an OECD average of 7.5%. These results show that the proportion of Indonesian students

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achieving high levels of scientific competence remains very low. Several factors contribute to this condition, including learning that is dominated by textbook content rather than direct experience, misconceptions caused by the failure to relate concepts to real-life contexts, and non-contextual instruction that limits students' ability to connect scientific knowledge with natural phenomena. Learning environments, classroom climate, habits, and reading interest also influence students' ability to answer scientific-literacy questions (Fuadi et al., 2020).

Consistent with the PISA findings, biology learning at the senior high school level still faces various challenges, particularly in teaching abstract and conceptual topics (Istiara & Arwita, 2025). In general, biology learning emphasizes science process skills, including observation, experimentation, and data presentation. Integrated science process skills include controlling variables, operationally defining variables, formulating hypotheses, interpreting data, conducting experiments, and constructing models (Senisum, 2021). Integrated science process skills represent higher-order thinking skills (HOTS). However, classroom learning remains largely theoretical, even though science process skills are central to modern science education (Diputera et al., 2024).

The implementation of biology practical work in schools continues to face challenges such as inadequate facilities, limited instructional time, and underutilized laboratories. These conditions often make learning primarily demonstrative and theoretical. Observations by the previous studied in senior high schools in Banyuwangi Regency revealed disparities in laboratory facilities and equipment quality, leading teachers to use demonstrations more frequently than independent practical work (Kurniawan, 2025). A similar condition was reported at SMA Negeri 1 Tinambung, where biology practical activities were not conducted because of limited facilities. Another factor was the difficulty of maintaining orderly student behavior during practical work, which increased the risk of damage to laboratory equipment (Indrasari, 2024).

These conditions indicate that direct experiential learning has not yet been fully facilitated. Therefore, an alternative learning approach is needed that can still develop scientific processes and conceptual understanding in a visual and interactive manner, one of which is the integration of virtual laboratories into structured learning materials. A preliminary study conducted through a diagnostic test on osmosis among Grade XI students showed that 48% of students did not yet understand the concept of osmosis accurately and 24.4% experienced misconceptions. One form of learning representation that can be used is a virtual laboratory that provides simulations of the osmosis process, enabling students to observe changes in conditions visually. The use of a virtual laboratory needs to be integrated into structured learning materials so that students can be guided through systematic scientific-process stages.

The previous studied examined the effectiveness of a Group Investigation model assisted by LabXchange in improving learning outcomes and reported an 82.9% increase in cognitive learning outcomes (Rahmawati & Pratiwi, 2024). Thedeveloped a blended-learning-based e-LKPD using the OLabs virtual laboratory to improve students' critical thinking on membrane transport and obtained very high validity (90.5%), very good student-response practicality (94.33%), and very good learning implementation (97.77%) (Zahro & Yuliani, 2024). The previous studied also reported a positive effect of OLabs on students' biology learning outcomes (Ahmad et al., 2024). These studies indicate that virtual laboratories can improve learning outcomes and students' thinking skills. However, studies developing a scientific

Student Worksheet (LKPD) that integrates a virtual laboratory with hands-on practical activities to improve conceptual understanding of osmosis remain limited.

Based on this gap, the novelty of this study lies in the development of a scientific LKPD that integrates the OLabs virtual laboratory with hands-on practical work within a single learning resource. The virtual laboratory is used as an initial visualization of the osmosis process before the practical activity, with the aim of helping students build conceptual representations that enable them to explain osmosis phenomena in everyday life. The developed learning material was aligned with indicators of conceptual understanding of osmosis and designed according to the stages of the scientific approach. This approach is consistent with the idea of deep learning, which emphasizes in-depth conceptual understanding, the development of critical thinking skills, and students' construction of new knowledge.

Method

This study employed a Research and Development (R&D) method using the 4D development model developed by (Thiagarajan, 1974). Consisting of Define, Design, Develop, and Disseminate. The Define stage included curriculum analysis, concept analysis, student-characteristic analysis, task analysis, and formulation of learning objectives. The Design stage included the preparation of the LKPD and research instruments. The Develop stage included expert validation, product revision, and a limited trial to obtain data on the validity, practicality, and effectiveness of the LKPD. The Disseminate stage was carried out through publication in the form of a scientific article.

The population comprised all Grade XI students at SMA Negeri 1 Waru who had received instruction on osmosis. The sample consisted of 36 students from one Grade XI class selected through purposive sampling based on teacher recommendations and conformity with the study criteria. The limited trial was conducted in April 2026 at SMA Negeri 1 Waru.

The data-collection instruments consisted of a validation sheet covering technical requirements, didactic requirements, construction requirements, scientific-approach stages, and achievement of conceptual-understanding objectives. A student-response questionnaire assessed appearance and language, learning, use, and benefits. The learning-implementation observation sheet covered the introductory activities and the stages of the scientific approach. The final instrument was a pretest-posttest evaluation sheet consisting of multiple-choice and essay questions. These instruments were used to determine the validity, practicality, and effectiveness of the developed product.

Validity was assessed by three expert validators. Validation analysis used a four-point Likert scale: 1 (poor), 2 (fair), 3 (good), and 4 (very good). Practicality was determined from the student-response questionnaire and the learning-implementation observation sheet. The student-response questionnaire was completed by the 36 Grade XI students at SMA Negeri 1 Waru who participated in the study, while implementation was assessed by an observer during the limited trial. Practicality analysis used a Guttman scale, with 1 representing a positive response (Yes) and 0 representing a negative response (No). Effectiveness was determined from students' pretest and posttest scores and subsequently analyzed using N-Gain.

The validity of the developed product was analyzed using the validity percentage formula adapted from (Sunarto & Riduwan, 2017). The obtained validity percentage was then interpreted based on the validity criteria presented in Table 1. These criteria were used to

determine whether the product met the required level of validity before proceeding to the next stage of the development process.

Table 1. *Validity Criteria*

Percentage (%)	Category
0–40	Invalid
41–55	Less Valid
56–70	Moderately Valid
71–85	Valid
86–100	Highly Valid

The practicality of the developed product was analyzed using the practicality percentage formula adapted from (Sunarto & Riduwan, 2017). The resulting practicality percentage was interpreted according to the practicality criteria presented in Table 2. These criteria were employed to evaluate the ease of use and implementation of the developed product during the learning process.

Table 2. Practicality Criteria

Percentage (%)	Category
0–40	Impractical
41–55	Less Practical
56–70	Moderately Practical
71–85	Practical
86–100	Highly Practical

The effectiveness of the developed product was determined using the N-Gain score formula developed by (Moiyo et al., 2024). The calculated N-Gain score was interpreted according to the effectiveness criteria shown in Table 3. The interpretation was used to classify the improvement in students' learning outcomes into high, moderate, or low categories.

Table 3. *N-Gain Score Interpretation*

N-Gain Score (g)	Category
$0.7 < g \leq 1.0$	High
$0.3 < g \leq 0.7$	Moderate
$0.0 < g \leq 0.3$	Low

Table 3 presents the interpretation criteria for the N-Gain scores used to determine the level of improvement in students' learning outcomes. The N-Gain score is divided into three categories: high, moderate, and low. An N-Gain score of $0.7 < g \leq 1.0$ is categorized as high, indicating substantial improvement in students' learning outcomes. A score of $0.3 < g \leq 0.7$ is classified as moderate, indicating a moderate level of improvement, while a score of $0.0 < g \leq 0.3$ is categorized as low, indicating limited improvement. These categories provide a basis for evaluating the effectiveness of the learning product in improving students' learning outcomes.

Results

Define Stage

During the Define stage, an initial analysis was conducted, including classroom observation, a diagnostic test, curriculum analysis, student analysis, task analysis, concept analysis, and formulation of learning objectives as the basis for developing the LKPD. The observations showed that osmosis learning still faced limitations in visualizing the movement of water across membranes, making it difficult for students to develop a comprehensive conceptual understanding. The diagnostic test also showed that 48% of students did not yet

understand osmosis accurately and 24.4% experienced misconceptions, indicating the need for learning materials that can better support conceptual understanding.

Curriculum analysis showed that osmosis within the Kurikulum Merdeka requires students to understand cellular bioprocesses, including osmosis. Based on the analysis of student characteristics, students had already studied the prerequisite topic of membrane transport; therefore, the LKPD development focused on strengthening conceptual understanding of osmosis. Task analysis was subsequently conducted by designing learning activities according to the stages of the scientific approach: observing, questioning, experimenting, associating, and communicating. Concept analysis produced an osmosis concept map that served as the basis for organizing the LKPD content. Based on these analyses, learning objectives were formulated as a reference for developing the scientific LKPD based on the OLabs virtual laboratory.

Design Stage

During the Design stage, an initial design of the scientific LKPD based on the OLabs virtual laboratory was prepared using the results of the Define stage. The LKPD design included an introductory section and learning activities structured according to the scientific approach: observing, questioning, experimenting, associating, and communicating. The observing activity used an osmosis simulation in the OLabs virtual laboratory as a conceptual visualization before the hands-on practical activity, while subsequent activities guided students to conduct the practical work, analyze the results, and formulate conclusions about osmosis according to indicators of conceptual understanding. The LKPD layout, including the cover, identity section, instructions for use, concept map, and learning-activity sheets, was also designed as the basis for product development in the Develop stage.

Develop Stage

During the Develop stage, the LKPD was refined through revision, expert validation, and a limited trial until a final product suitable for use in learning was obtained. The outcomes of this stage included the developed LKPD and data on its validity, practicality, and effectiveness.

Development of the Scientific LKPD Based on the OLabs Virtual Laboratory

The developed scientific LKPD based on the OLabs virtual laboratory consisted of an introductory section and learning activities. The introductory section contained the cover, general information, and a concept map, while the osmosis learning activities were organized according to the scientific approach with support from the OLabs virtual laboratory. The developed LKPD is shown in Figure 1.

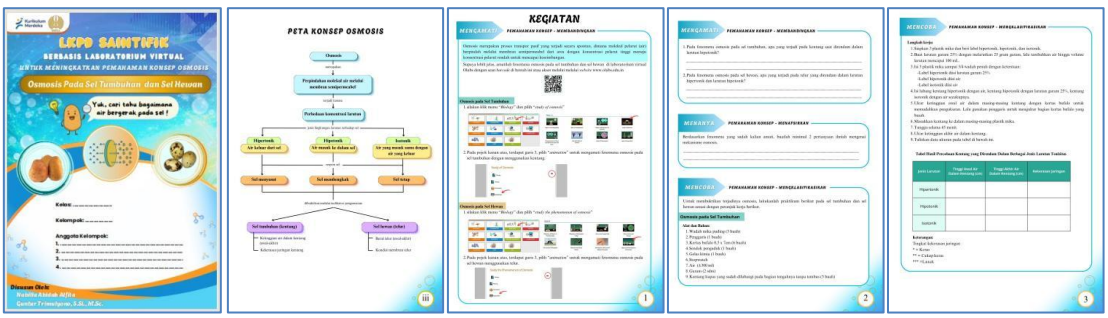


Figure 1. *Display of the Developed LKPD*

The LKPD consisted of an introductory section and a core learning-activity section. The introductory section contained the cover, table of contents, osmosis concept map, instructions

for using the LKPD, and LKPD identity. The core section contained a sequence of osmosis learning activities organized according to the scientific approach: observing involved an osmosis simulation on the OLabs website; questioning required students to formulate scientific questions about the osmosis mechanism; experimenting provided guidance for hands-on practical work; associating contained questions based on the results of the activities; and communicating required students to formulate conclusions and produce the assigned learning product.

Validity of the Scientific LKPD Based on the OLabs Virtual Laboratory

The LKPD was evaluated by three validators consisting of two biology lecturers and one biology teacher from SMA Negeri 1 Waru. The product-validity results are presented in Table 1.

Table 4. *Summary of LKPD Validity Data*

Aspect Assessed	Validity Percentage (%)	Criteria
Technical Requirements	95.83	Highly Valid
Didactic Requirements	85	Valid
Construction Requirements	93.75	Highly Valid
Scientific Approach Stages	97.91	Highly Valid
Achievement of Conceptual Understanding	90.28	Highly Valid
Average	93.13	Highly Valid

As shown in Table 4, the average validity percentage was 93.13%, which met the highly valid criterion. This result indicates that the developed product met the feasibility criteria based on validator assessments. Among the assessed aspects, the scientific-approach stages received the highest percentage, 97.91%, and were classified as highly valid. The technical requirements received 95.83%, construction requirements 93.75%, and achievement of conceptual understanding 90.28%, all of which were also classified as highly valid. The didactic-requirements aspect received the lowest score, 85%, and was classified as valid. Overall, all aspects fell within the valid to highly valid categories, indicating that the developed LKPD was suitable for use in the trial stage.

Practicality of the Scientific LKPD Based on the OLabs Virtual Laboratory

The practicality of the LKPD was evaluated based on student responses and learning implementation during the limited trial. Data were obtained through a student-response questionnaire and a learning-implementation observation sheet completed by an observer. The student-response results are presented in Table 5.

Table 5. *Summary of Student Responses to the Use of the LKPD*

Aspect Assessed	Practicality Percentage (%)	Criteria
Appearance and Language	95.14	Highly Practical
Learning	91.67	Highly Practical
Use and Benefits	92.59	Highly Practical
Average	93.13	Highly Practical

As shown in Table 5, student responses to the scientific LKPD based on the OLabs virtual laboratory produced an average practicality percentage of 93.13%, which met the highly practical criterion. The appearance and language aspect obtained the highest percentage at 95.14%. The use and benefits aspect obtained 92.59%, while the learning aspect obtained 91.67%. All aspects were classified as highly practical. In addition to student responses, learning implementation was evaluated through observation during the learning process. The observation results are presented in Table 6.

Table 6. *Summary of Learning-Implementation Observations*

Phase	Practicality Percentage (%)	Criteria
Introduction	98.61	Highly Practical
Phase 1: Observing	97.22	Highly Practical
Phase 2: Questioning	97.22	Highly Practical
Phase 3: Experimenting	98.61	Highly Practical
Phase 4: Associating	89.81	Highly Practical
Phase 5: Communicating	93.05	Highly Practical
Average	95.14	Highly Practical

As shown in Table 6, the observation of learning implementation using the scientific LKPD based on the OLabs virtual laboratory produced an average practicality percentage of 95.14%, classified as highly practical. The introductory phase and Phase 3, Experimenting, obtained the highest percentages at 98.61%. Phase 1, Observing, and Phase 2, Questioning, each obtained 97.22%, while Phase 5, Communicating, obtained 93.05%. The lowest percentage was obtained in Phase 4, Associating, at 89.81%, although it remained within the highly practical category. Overall, the observations indicated that all learning stages were implemented at a highly practical level.

Effectiveness of the Scientific LKPD Based on the OLabs Virtual Laboratory

The effectiveness of the LKPD was assessed based on improvement in students' conceptual understanding, analyzed using the percentage of students achieving the mastery criterion of >=79 and the N-Gain score derived from pretest and posttest results. A summary is presented in Table 7.

Table 7*. Mastery Percentage and N-Gain*

Pretest Mastery Percentage (%)	Posttest Mastery Percentage (%)	N-Gain	N-Gain Criterion
33	97.2	0.88	High

As shown in Table 7, the percentage of students achieving learning mastery increased after using the scientific LKPD based on the OLabs virtual laboratory. The mastery percentage increased from 33% on the pretest to 97.2% on the posttest. The N-Gain score was 0.88, which was classified as high. The increase in mastery from pretest to posttest indicates that most students achieved the learning-mastery criterion after participating in learning with the developed LKPD. The mastery percentages for each indicator of conceptual understanding are presented in Figure 2.

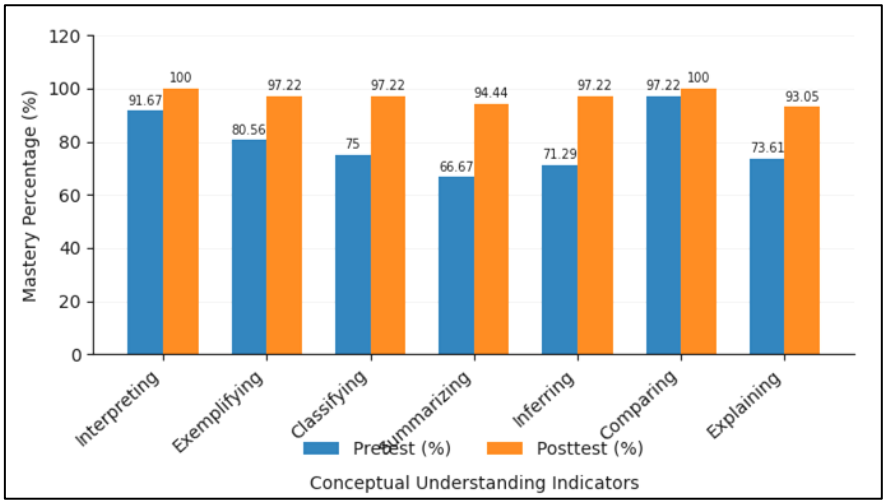


Figure 2. *Percentage of Learning Mastery for Each Indicator of Conceptual Understanding*

For the interpreting indicator, the mastery percentage increased from 91.67% on the pretest to 100% on the posttest. The exemplifying indicator increased from 80.56% to 97.22%, while the classifying indicator increased from 75% to 97.22%. For summarizing, mastery increased from 66.67% to 94.44%. The inferring indicator increased from 71.29% to 97.22%, while comparing increased from 97.22% to 100%. The explaining indicator increased from 73.61% on the pretest to 98.05% on the posttest. Overall, these data indicate improvement in students' conceptual understanding across all indicators. The largest increases were observed in summarizing and inferring, while interpreting and comparing achieved the highest posttest mastery percentages, reaching 100%.

Disseminate Stage

During the Disseminate stage, the developed LKPD, which had been declared valid, practical, and effective, was disseminated through publication in a scientific article. This stage aimed to communicate the research findings to the academic community so that they could serve as a reference for the development of virtual-laboratory-based learning materials on osmosis.

Discussion

Based on the analysis, osmosis was selected because it contains abstract concepts that require visualization to make them easier for students to understand (Junanah et al., 2024). The movement of a solvent through a semipermeable membrane cannot be directly observed; therefore, learning media are needed to help students understand the mechanism of osmosis more concretely (Zaradiva et al., 2025). For this reason, the OLabs virtual laboratory was used to provide an initial visualization of osmosis before students conducted hands-on practical work. The core learning activities were organized according to the stages of the scientific approach. In the first stage, observing, students accessed an OLabs virtual-laboratory simulation of osmosis in plant and animal cells. This activity helped students develop an initial visualization of water movement under hypertonic, hypotonic, and isotonic conditions. Virtual laboratories can support students in understanding processes that are difficult to observe directly or concretely (Mukin et al., 2025).

Validation by three validators showed that the developed product achieved a validity percentage of 93.13%, classified as highly valid. This result indicates that the components of the LKPD met the established feasibility criteria in terms of technical, didactic, and construction requirements as well as alignment with the learning objectives. The previous studied state that assessment aspects should be aligned with the needs and objectives of the study (Cahaya et al., 2024). The high validity score indicates that the product was designed in accordance with learning needs and student characteristics.

For the technical-requirements aspect, the scientific LKPD obtained a validity percentage of 95.83%, classified as highly valid. This result indicates that the LKPD display met the criteria for effective learning materials, including cover design, font readability, text size, clarity of instructions, learning objectives, and completeness of LKPD identity information. From the perspective of learning-material development, strong technical design can increase students' learning interest and facilitate understanding because a clear and systematic presentation helps reduce cognitive load (Mukhzamilah, 2023). The highly valid score in this aspect indicates that the developed LKPD has a communicative and user-friendly presentation.

The didactic-requirements aspect obtained a score of 85%, classified as valid, although it was relatively lower than the other aspects. Revisions focused on the accuracy of the osmosis concept, highlighting important information, clarifying virtual-laboratory procedures, and improving the alignment between questions and answer keys to reduce potential misconceptions and strengthen the LKPD's support for independent conceptual understanding. This is consistent with the previous studied, who state that an LKPD should facilitate observation, practical work, and connections between observational results and scientific concepts (Qolbi et al., 2025).

The construction-requirements aspect achieved a validity percentage of 93.75%, classified as highly valid. This result indicates that the language used in the LKPD complied with the Indonesian Spelling Guidelines (PUEBI), used terms that were understandable to students, and employed simple, unambiguous sentence structures. Clear language is essential in learning materials because it helps students understand instructions and learning concepts more effectively (Juriah et al., 2025). Accurate language can also minimize misconceptions and improve learning effectiveness (Taha, 2025). Thus, the developed LKPD met appropriate construction requirements as a learning resource. The scientific-approach stages obtained a validity percentage of 97.91%, classified as highly valid. This indicates that the stages of the scientific approach were systematically structured and aligned with the learning objectives. Learning that actively involves scientific processes can improve students' conceptual understanding (Masihu et al., 2025). Therefore, the high validity score for this aspect indicates that the LKPD successfully integrated the scientific-approach stages.

The aspect concerning achievement of the objective of improving conceptual understanding obtained a score of 90.28%, classified as highly valid. This aspect included the conceptual-understanding indicators of comparing, interpreting, classifying, explaining, exemplifying, summarizing, and inferring. The validation results showed that each stage of the LKPD was directed toward practicing these indicators. During observing, students compared the responses of plant and animal cells under different solution conditions. The questioning stage helped students interpret osmosis phenomena through scientific questions. The experimenting stage trained students to classify observations according to solution type. The associating stage helped students explain the relationship between practical results and the concept of osmosis and provide examples of its application in everyday life.

During communicating, students practiced summarizing and drawing inferences from the learning activities. According to the conceptual-understanding taxonomy, understanding is not limited to recalling content but includes interpreting, classifying, explaining, and drawing conclusions. Therefore, the validation results indicate that the developed LKPD was appropriate for supporting students' conceptual understanding of osmosis. The student-response questionnaire yielded a practicality score of 93.13%, classified as highly practical, while the learning-implementation observation yielded 95.14%, also classified as highly practical. These high percentages indicate that the LKPD was easy to use, attractive to students, and able to support the implementation of learning according to the planned design. The previous studied states that student responses can be used to evaluate the ease of use, usefulness, and attractiveness of learning media (Hidayatullah & Ramadhanti, 2026). In addition, high implementation results indicate that each stage of learning can be carried out effectively in accordance with the established syntax (Sarah & Arwita, 2025).

Based on the student-response questionnaire, the appearance and language aspect obtained a practicality percentage of 95.14%, classified as highly practical. This result indicates

that students considered the LKPD visually attractive, found the illustrations helpful for understanding the material, and regarded the language as easy to understand. Attractive learning materials can increase students' attention and motivation, thereby supporting conceptual understanding (Setiawan, 2023). For the learning aspect, the scientific LKPD obtained a practicality percentage of 91.67%, classified as highly practical. This result indicates that the LKPD supported students' engagement in learning and helped them understand osmosis more effectively. This finding is consistent with previous studied, who states that conceptual understanding develops more optimally when students actively participate in learning activities that provide direct learning experiences (Setyaki, 2024).

The use and benefits aspect obtained a practicality percentage of 92.59%, classified as highly practical. This indicates that the OLabs virtual laboratory was considered easy to access, provided simulations that corresponded to real experiments, and helped students understand osmosis more effectively. Visualization through animation and simulation can facilitate understanding of abstract concepts because information is presented in a more concrete and interactive form (Nuzalifa et al., 2025). In addition to student responses, learning implementation was evaluated through observation during the learning process. In this study, the observer was a non-participant observer who was not directly involved with the research subjects (Sugiyono, 2022). The observation results showed an implementation percentage of 95.14%, classified as highly practical. The lowest percentage was obtained in the associating stage at 89.81%, although it still met the highly practical criterion. The associating stage requires students to analyze observations, connect the information obtained, and draw conclusions based on the available data. These activities require higher-order thinking and therefore demand more time and guidance than other stages.

Consequently, implementation in this stage tended to be lower than in the other stages. This pattern is also consistent with Putri (2016), who found that applying Guided Discovery to train students' science skills required more implementation time. Overall, the observation results indicate that the learning stages in the LKPD could be implemented effectively in accordance with the scientific approach. The effectiveness of the scientific LKPD was reflected in the improvement in students' learning achievement. Before learning, most students had not met the established mastery criterion. After learning, almost all students achieved the mastery standard. This improvement was reflected in the mastery percentage, which increased from 33% to 97.2%, accompanied by an average N-Gain score of 0.88, classified as high. These findings indicate that integrating the scientific approach with a virtual laboratory can help students develop a stronger conceptual understanding of osmosis. Learning media designed according to the characteristics of the topic and the needs of learners have the potential to support optimal conceptual understanding. This result is supported by previous studied, who also found that the use of Visme digital media improved students' learning outcomes (Febriansyah et al., 2023).

The substantial improvement in learning outcomes was supported by students' active engagement in each stage of the scientific approach embedded in the LKPD. Through these stages, students did not merely receive information from the teacher; they also had opportunities to observe phenomena, conduct experiments, analyze results, and independently formulate conceptual conclusions. Active student engagement in learning can improve scientific thinking and conceptual understanding (Masihu et al., 2025). The effectiveness of the LKPD was also supported by improved mastery across each indicator of conceptual understanding, as analyzed from the pretest and posttest results. Improvement in each indicator suggests that the LKPD helped students not only memorize concepts but also

understand, interpret, and apply osmosis concepts in different situations. Students are considered to understand a concept when they can explain the material in their own words (Samaduri, 2022). Therefore, improvement across all indicators indicates that learning with the LKPD supported the comprehensive development of students' conceptual understanding. Overall, the results indicate that the scientific LKPD based on the OLabs virtual laboratory was effective in improving students' conceptual understanding of osmosis. Its effectiveness was demonstrated by increased learning mastery, the high N-Gain score, and improved mastery across all indicators of conceptual understanding. Thus, the developed LKPD was valid, practical, and effective in supporting osmosis learning.

Conclusion

Based on the results of this 4D development study, the scientific LKPD based on the OLabs virtual laboratory for osmosis met the criteria of highly valid, highly practical, and effective, indicating that it is feasible as an alternative learning resource for biology instruction at the senior high school level. The integration of virtual laboratory activities provides students with opportunities to visualize and explore the process of osmosis in an interactive learning environment, thereby supporting more meaningful conceptual understanding. However, the study was limited to a trial involving one class at a single school; therefore, the findings do not yet represent the use of the LKPD among students with more diverse characteristics, learning backgrounds, and educational contexts. The results indicate that integrating a virtual laboratory with hands-on practical work can support students' conceptual understanding of osmosis by connecting theoretical concepts with observable experimental phenomena. Future studies are therefore recommended to conduct trials on a broader scale involving multiple schools and diverse student groups, as well as to develop similar LKPDs for other biology topics characterized by abstract concepts. Such development may further support innovative, interactive, and student-centered biology learning.

Aknowledgment

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