JURNAL UPI

Assimilation: Indonesian Journal of Biology Education
ISSN 2621-7260 (Online)
Journal homepage: https://ejournal.upi.edu/index.php/asimilasi

Contribution of practical activities to students' science process skills and digital literacy about photosynthesis

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OPEN ACCESS

ARTICLE HISTORY
Received: 20 February 2026
First Revised: 17 March 2026
Accepted: 30 March 2026
First Available Online: 31 March 2026
Publication Date: 31 March 2026

KEYWORDS
Digital literacy
Local materials
Plant physiology
Science process skills
Virtually practical activity

ABSTRACT

Photosynthesis, as part of plant physiology, is an important topic, but students' mastery of the material remains low. One way to master learning material is through practical activity. Sometimes the laboratory facilities and equipment at school are inadequate, so practical activity can still be carried out using local materials and virtually. The aim of this study is to reveal the contributions of practical activity using local materials and virtual laboratories to students' science process skills and digital literacy. A quasi-experimental design was used in this study, with three experimental classes: class L1, which used local materials; class V1, which used the Olabs virtual laboratory; and class V2, which used the Melati virtual laboratory. The research was conducted at a high school in grade 12, and the sample consisted of 89 participants. The results show that students' science process skills in class L1 have reached a good level with an N-gain of 0.66; classes V1 and V2 have also reached good levels with N-gain values of 0.64 and 0.61, respectively. Likewise, students' digital literacy is at a good level, and both classes achieved N-gain in the medium category, with values of 0.54 and 0.59, respectively. Thus, implementing practical activities with local materials or virtual laboratories helps improve students' competency. Changes in students' science process skills are, on average, at the complementation level, whereas changes in digital literacy are at the revision level. To improve students' competency, practical equipment needs further development.

INTRODUCTION

Plant physiology is a branch of biology that is categorized as difficult for students (Arthur-Baidoo et al., 2022; Colthorpe et al., 2018; Diana, 2017; Diana et al., 2021; Fatmawati et al., 2024; Gloria et al., 2019), especially regarding metabolism material (Fauzi et al., 2021; Fauzi & Mitalistiani, 2018). Photosynthesis, as a part of metabolism material, has been recognized by experts as biological material that is very important to be mastered not only by students but also by the community, because mastery of plant physiology material can be used on an ecological scale (Chikov et al., 2021). Knowledge of plant physiology can be utilized in the scope of ecology and economics (Aboelyazeed et al., 2023; Eriksson et al., 2026; Jančaříková & Jančařík, 2022). On the other hand, many students still have misconceptions about this material (Atchia et al., 2024; Bizimana et al., 2024; Diana, 2017; Karakaya et al., 2021; Skribe Dimec & Strgar, 2017; Wynn et al., 2017) and mastery of the material is still low (Diana, 2017; Fatmawati et al., 2024; Gloria et al., 2019), even the phenomenon of plant awareness disparity/PAD emerged among students and the community (Hubbard, 2024; Parsley, 2020) and plant blindness (Franco-Mariscal & Fernández-González, 2021; Parsley, 2020) so it is necessary to intensify practical activities in learning (Vydra & Kováčik, 2025).

Practical activity can help students discover and prove theories (Purwanti & Fauzi, 2022). Practical activity even encourages students to hone their skills in communicating practical activity reports that have been carried out (Astuti & Suciati, 2017). In science subject, learning should be carried out experientially through experiments (Mirosavljević et al., 2023).

Laboratory activities implemented in teaching develop not only students' knowledge but also critical thinking, science process skills, and can also represent a tool leading to an understanding of the significance of plants (Schnell et al., 2021; Shin et al., 2021) . Through practical activity, it is also possible to develop accompanying impacts that are beneficial for the student learning process, namely the interaction between students and the teaching material, student interaction with practical teachers through various practical materials and supporting facilities, and interaction between students through various practical activities (Agustina & Rahmat, 2020). According to Ulfa et al. (2017) through the application of PPDP (Practicum, Presentation-discussion, Demonstration, and Presentation-discussion) learning strategies, students can understand the concept of photosynthesis through the discovery of many facts.

In reality, there are still many schools in Indonesia that have obstacles in providing laboratory facilities and equipment to carry out practical work, such as lack of necessary practical tools and materials, limited space, and outdated facilities (Prajoko et al., 2017). Therefore, in this study, the practical activity carried out in the laboratory used local materials. Another fact shows that the practical activity that was supposed to be carried out in the laboratory, could not be fully realized for various reasons, such as limited resources in the form of practical tools and materials, inadequate laboratory space, lack of time allocated for practical activities and students cannot repeat practical activities at home (Rosdianti & Paidi, 2021). Thus, in addition to being carried out in indoor and outdoor laboratories, sometimes practical activity must also be carried out virtually. From the research of Ramadhani et al. (2023) it was shown that through the interactive animation application, students more easily understand photosynthesis material.

The student competencies highlighted in this study are science process skills for both types of applied practical activity (local material and virtual laboratories) and digital literacy specifically for the implementation of virtual laboratories. Science process skills are one vehicle for teaching 21st century skills (Priyani & Nawawi, 2020) and many countries have emphasized science process skills in science learning curricula, starting from primary school to university (Kurniawati, 2021). Science process skills that are taught in science subjects are very important to every student as it is the first step to stimulate students to use thinking and creativity effectively (Houtz, 2013). Science process skills are a reflection of the methods used by scientists in producing comprehensive information about science such as product, attitude, process, and application dimensions (Widodo et al., 2022). The products of science learning are produced through the application of process

DOI: https://doi.org/10.17509/aijbe.v9i1.97369
e-ISSN 2621-7260

skills in learning either classroom or laboratory. The importance of science process skills has been discussed for over 23 years, yet the actual condition, especially in Indonesia, shows that many students still lack mastery of science process skills (Hardianti & Permatasari, 2023).

Digital literacy skills are the ability to use and understand information from various formats (Gilster, 1997). Digital literacy is an individual's ability to use functional skills on digital devices so that they can be creative, critical thinking, collaboration with others, communication effectively, find and select information, and maintaining electronic security and evolving socio-cultural context (Payton & Hague, 2010). Digital literacy is also one of the skills that everyone must have to face 21st century learning (Widodo et al., 2022). However, the Indonesian Digital Literacy Index in 2021 according to Katadata Insight Center (KIC) and the Ministry of Communication and Information, still in the unsatisfactory category (Katadata Insight Center, 2022). One way to teach digital literacy skills is by implementing virtual laboratories in school learning. Improving digital literacy skills through the use of virtual laboratories can be seen from research conducted by (Listiawati et al., 2022)

Many studies have been conducted on students' science process skills in the field of science, among them are (Agustiani et al., 2022; Akani, 2015; Anjugam & Chellamani, 2022; Derilo, 2019; Diana, 2023; Hardianti & Permatasari, 2023). Among the many studies, there are still few that reveal students' science process skills through the implementation of plant physiology (photosynthesis) practical activity in a unique and innovative way, that is using local materials and virtual laboratories. Specifically, for virtual laboratory, the digital literacy of students is also revealed. This methodological gap will likely have an impact on the emergence of theoretical gaps, namely that learning outcomes often do not match theoretical predictions, which can be caused by limited facilities (Alfiah & Bramastia, 2023), the tendency for practicums to be too procedural and lack follow-up, and a lack of student cognitive involvement (Rayment et al., 2023).

Previous research has not shown much of changes in student competencies, so this research attempts to trace changes in student competencies by adopting Lappi (2013) with some modifications. Thus, the research question is how does the photosynthesis practical activity (which uses local materials and virtual laboratories) contribute to student competencies, which include science process skills and digital literacy?

METHODS

Research Design

This research uses the quasi-experiment method with three experimental classes, namely experimental class 1 (L1), which uses local material, experimental class 2 (V1), which uses the OLabs virtual laboratory, and experimental class 3 (V2), which uses the Melati virtual laboratory. The sample was taken using a purposive sampling technique, with class XII as the criterion because the photosynthesis material is in class XII, and they are not yet familiar with the use of the OLabs virtual laboratory and the Melati virtual laboratory. Additionally, the classes were taught by the same biology teacher.

Each class was given a pre-test on science process skills on the topic of photosynthesis before the treatment, and then a post-test of science process skills was given after the treatment. Specifically, for the experimental classes V1 and V2, in addition to being given pre-tests and post-tests on science process skills, they were also given pre-tests and post-tests on digital literacy. Digital literacy was assessed exclusively in classes V1 and V2, as this competency is directly associated with the use of interactive digital technology during virtual laboratory activities. Class L1, which conducted photosynthesis experiments using local materials in a physical laboratory setting, did not involve direct interaction with computer software or interactive multimedia. Therefore, measuring digital literacy in class L1 would not be contextually relevant to the learning activities carried out, and its exclusion was a deliberate methodological decision rather than an oversight. This design limitation is acknowledged, as it results in an asymmetrical comparison

DOI: https://doi.org/10.17509/aijbe.v9i1.97369
e-ISSN 2621-7260

across the three classes with respect to digital literacy outcomes. The research design is presented in Table 1.

Table 1

Research design.

Group	Pretest	Treatment	Posttest
Experiment 1 (L1)	O_1	X_1	O_2
Experiment 2 (V_1)	$O_{1,3}$	X_2	$O_{2,4}$
Experiment 3 (V2)	$O_{1,3}$	X_3	$O_{2,4}$

L_1 : Experimental group with local material laboratory implementation
V_1 : Experimental group with the implementation of the OLabs virtual laboratory
V_2 : Experimental group with the implementation of the Melati virtual laboratory
O_1 : Pre-test of students' science process skills on the topic of photosynthesis
O_2 : Post-test of students' science process skills on the topic of photosynthesis
$O_{1,3}$: Pre-test of science process skills and digital literacy of students on the material of photosynthesis
$O_{2,4}$: Post-test of science process skills and digital literacy s of students on the material of photosynthesis
X_1 : Treatment with the implementation of local material in the laboratory
X_2 : Treatment with the implementation of the OLabs virtual laboratory
X_3 : Treatment with the implementation of the Melati virtual laboratory

Population and Samples

The population in this study is twelfth-grade students from one of the high schools in Bandung City. The sample in this study consists of three classes with a total of 89 students: 29 in class L1, 31 in class V1, and 29 in class V2.

Instruments

Data of students' science process skills were obtained through tests in the form of multiple-choice questions that refer to aspects of science process skills according to (Bailer et al., 1995) namely observation, identifying variables, formulating hypotheses, predicting, interpreting and communicating related to photosynthesis practicums. Based on the results of the trial of the science process skills instrument, overall it has a reliability value of 0.88 and is included in the high category and validity of 0.58 which is included in the sufficient category. Apart from pre-tests and post-tests, data on students' science process skills were also obtained from worksheets.

Student digital literacy refers to students' ability to use interactive multimedia technology in virtual laboratories, according to (Payton & Hague, 2010), which covers functional skills and beyond, the ability to find and select information, critical thinking and evaluation, cultural and social understanding, and collaboration. Students' digital literacy is measured using a test instrument in the form of multiple-choice items. Based on the results of the trial of the digital literacy instrument, overall it has a reliability value of 0.61 and is included in the high category and validity of 0.49 which is included in the sufficient category.

Procedures

Local material-based photosynthesis practical activity is a practical activity that uses tools and materials that are easily available in the students' surrounding environment and can substitute for laboratory equipment. The local material practical activity using photosynthesis material is the Ingenhousz and Sachs experiment. The local materials used in this research are plastic bags as containers for Hydrilla sp., cake soda as a substitute for $NaHCO3$, betadine as a substitute for Lugol's solution, bleach as a substitute for alcohol, and an electric pot as a heater.

DOI: https://doi.org/10.17509/aijbe.v9i1.97369
e-ISSN 2621-7260

The virtual laboratory used in this research is computer software that is operated using a computer with an interactive multimedia base, consisting of a series of laboratory tools, and can simulate activities in a real laboratory. In this study, the virtual laboratories used were the OLabs virtual laboratory and the Melati virtual laboratory. The OLabs virtual laboratory can be accessed via the link https://www.olabs.edu.in/, while the Melati virtual laboratory can be accessed via the link https://vlab.bmtmelati.com/. These two virtual laboratories were chosen because they have the same aspects of the practical activity, starting from theory, procedure, animation, simulator, video, self-evaluation, resources, and feedback, only different in appearance.

Data Collection and Analysis

The pre-test and post-test data on students' science process skills and digital literacy were analyzed using descriptive statistics, including the calculation of average scores. Furthermore, the data were categorized according to the criteria proposed by (Arikunto, 2013), as presented in Table 2.

Table 2

Science process skills assessment categories Arikunto (2013).

Score	Category
> 85	Very Good
70 – 85	Good
55 – 70	Moderate
40 – 55	Low
> 40	Very Low

After obtaining the results of the pre-test and post-test of students' science process skills and digital literacy, the N-Gain value was calculated to analyse the improvement from the pre-test and post-test, using Hake's rules (1998) (Table 3).

Table 3.

N-Gain categories Hake (1998)

N-Gain Value	Category
N-Gain > 0,7	High
0,3 ≤ N-Gain ≥ 0,7	Medium
N-Gain < 0,3	Low

This study also revealed the classification of changes in student competencies, both in terms of science process skills and digital literacy, from pre-test to post-test by adopting Lappi (2013) with some modifications. According to Lappi (2013), conceptual-level change consists of 5 levels: Construction (Co), Revision (R), Complementation (Cp), Static (S), and Disorientation (D). The interpretation of the Construction (Co) level is that students can do skill construction, while the Revision (R) level is that students can revise their skill. If students can integrate new skills with initial skills into comprehensive skills, then it is included in the Complementation level (Cp). If students can't change existing skills into better skills, then it is said to enter the static level (S). If students experience changes in skill that are worse than the initial skill, it is called Disorientation (D).

DOI: https://doi.org/10.17509/aijbe.v9i1.97369
e-ISSN 2621-7260

RESULTS AND DISCUSSION

Contribution of Practical Activity to Students' Science Process Skills

Research data in the form of average scores of students' science process skills in experimental class L1 (photosynthesis practical activity using local materials) are shown in Table 4. Data regarding the average score of students' science process skills in experimental class V1 (photosynthesis practical activity using the OLabs virtual laboratory) and class V2 (photosynthesis practical activity using the Melati virtual laboratory), respectively, are listed in Tables 5 and 6.

Table 4

Average score of students' science process skills in experimental class L1.

Science Process Skills Indicator	Science Process Skills Score				
	Pre-test	Worksheet1	Worksheet2	Post-test	N-Gain
1. Differentiating	70.11 (Good)	91.95 (Very Good)	96.55 (Very Good)	89.65 (Very Good)	0.63 (Medium)
2. Identifying Variables	39.65 (Very Low)	89.65 (Very Good)	93.10 (Very Good)	82.75 (Good)	0.71 (High)
3. Predicting	64.36 (Moderate)	97.70 (Very Good)	96.55 (Very Good)	82.75 (Good)	0.58 (Medium)
4. Formulating Hypothesis	60.91 (Moderate)	86.20 (Very Good)	83.90 (Good)	83.90 (Good)	0.62 (Medium)
5. Communicating	67.81 (Moderate)	73.98 (Good)	87.35 (Good)	85.05 (Very Good)	0.50 (Medium)
6. Interpreting	60.34 (Moderate)	81.60 (Good)	83.90 (Good)	81.89 (Good)	0.56 (Medium)
Average	59.48 (Moderate)	86.85 (Very Good)	90.23 (Very Good)	84.14 (Good)	0.66 (Medium)

Table 5

Average score of students' science process skills in experimental class V1.

Science Process Skills Indicator	Science Process Skills Score			
	Pre-test	Worksheet1	Post-test	N-Gain
1. Differentiating	76.34 (Good)	-	91.40 (Very Good)	0.67 (Medium)
2. Identifying Variables	61.29 (Moderate)	89.25 (Very Good)	83.87 (Good)	0.62 (Medium)
3. Predicting	46.24 (Very Low)	83.87 (Good)	79.57 (Good)	0.68 (Medium)
4. Formulating Hypothesis	43.01 (Very Low)	86.02 (Very Good)	75.27 (Good)	0.62 (Medium)
5. Communicating	67.74 (Moderate)	73.11 (Good)	86.02 (Very Good)	0.58 (Medium)
6. Interpreting	66.13 (Moderate)	72.04 (Good)	85.48 (Very Good)	0.57 (Medium)
Average	60,48 (Moderate)	80.86 (Good)	83,55 (Good)	0,64 (Medium)

Note: -: No data

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e-ISSN 2621-7260

From Table 4, Table 5, and Table 6, it can be seen that the average score of students' science process skills before the photosynthesis practical activity was classified as moderate, namely ranging from 58.97 to 60.48, and after the practical activity was carried out, it became good with an average score of 83.38 to 84.14. The science process skills of students in the good category differ from those of high school students in Bojonegoro, Central Java, as measured by the Program for International Assessment (PISA) test questions (Agustiani et al., 2022). Likewise, final year students in Nigeria obtained low integrated science process skills scores (Akani, 2015), and elementary school students on the Indonesian-Malaysian border (Priyani & Nawawi, 2020), high school students in Banjarmasin (Kusuma & Rusmansyah, 2021), junior high school students in Makassar (Sufinasa et al., 2023), and lower secondary students in Merbau Island (Zulirfan et al., 2018) also have low science process skills. The results of this study show that students' science process skills can increase significantly as the research results of (Aripin & Suryaningsih, 2021; Astuti, 2019; Fauzi et al., 2021; Hardianti & Permatasari, 2023; Rosdianti & Paidi, 2021; Rusliati & Retnowati, 2019; Utami et al., 2021).

Table 6

Average score of students' science process skills in experimental class V2.

Science Process Skills Indicator	Science Process Skills Score			
	Pre-test	Worksheet1	Post-test	N-Gain
1. Differentiating	82.76 (Good)	-	93.10 (Very Good)	0.63 (Medium)
2. Identifying Variables	37.07 (Very Low)	85.05 (Very Good)	76.72 (Good)	0.70 (Medium)
3. Predicting	48.28 (Low)	75.86 (Good)	75.86 (Good)	0.57 (Medium)
4. Formulating Hypothesis	36.78 (Very Low)	83.9 (Good)	72.41 (Good)	0.63 (Medium)
5. Communicating	74.71 (Good)	75.86 (Good)	88.51 (Very Good)	0.54 (Medium)
6. Interpreting	75.86 (Good)	70.11 (Good)	88.79 (Very Good)	0.53 (Medium)
Average	58,97 (Moderate)	78.16 (Good)	83,38 (Good)	0,61 (Medium)

Note: -: No data

Before carrying out the photosynthesis practicum, either by utilizing local materials (class L1) or by using a virtual laboratory, students' science process skills showed the lowest category (very low) in the skill of identifying variables (Table 4; Table 6), followed by the ability to formulate hypotheses (Table 5; Table 6). Meanwhile, the ability considered less good is the science process skill of predicting (Tables 5 and 6). In the pre-test for class L1, students were given several questions requiring them to identify the independent and dependent variables in the Ingenhousz and Sachs experiment. It turns out that fewer than 40% of students were able to answer (Table 4) that adding NHCO3 to the Ingenhousz experiment could serve as an independent variable. According to Amelia et al. (2024) NHCO3, which binds with H2O, produces CO2; CO2 itself is essential in photosynthesis as the main reactant (Habibillah, 2023; Leister, 2023).

In one of the pre-test questions in class V2, a picture of the virtual laboratory of Ingenhousz's photosynthesis experiment was presented, and students had to identify the variables based on the illustration. Only about 37% of students can answer it, namely, the color of light can be an independent variable in the process of photosynthesis. According to Hasanah et al. (2018) the color spectrum affects the photosynthesis process. In class V2, in questions with the indicator of

DOI: https://doi.org/10.17509/aijbe.v9i1.97369
e-ISSN 2621-7260

formulating a hypothesis, students are required to formulate a hypothesis based on discourse related to Ingenhousz's photosynthesis experiment. On average, only 37% of students were able to formulate a hypothesis based on the discourse (Table 6) that the rate of photosynthesis peaks at a certain light intensity. This is consistent with the statement by Taiz et al. (2018) that CO2 assimilation increases at specific light intensities.

During the practical activity, students are asked to complete worksheets by answering questions that assess science process skills. In class, L1 students are asked to complete worksheet 1 on Ingenhousz photosynthesis and worksheet 2 on Sachs photosynthesis. On average, from worksheets 1 and 2, students were able to answer questions about science process skills in the very good category (Table 4). The highest science process skills obtained were in the ability to predict, namely 97.70 in worksheet 1 and 96.55 in worksheet 2. In worksheet 1, students are asked to predict if more than 1 gram of baking soda is added, and the photosynthesis lab equipment is stored in a place exposed to sunlight. Meanwhile, in worksheet 2, students are asked to predict if a completely covered leaf is stored in a place exposed to sunlight. Almost all students can answer that adding more baking soda is likely to produce more bubbles, and that leaves completely covered will not produce starch. This is in accordance with the results of research by Amelia et al. (2024) and Nasution et al. (2025) that the addition of NHCO3 or baking soda at certain concentrations will increase the rate of photosynthesis. The student's prediction is consistent with the research results of Agung (2022), which showed that leaves covered with aluminum foil and then tested with Lugol's solution did not turn dark, indicating that starch was not formed as a result of the Sachs test.

In class V1, students are asked to fill out a worksheet about a photosynthesis practical activity using the OLabs virtual laboratory, and in class V2, using the Melati virtual laboratory. On average, students from both classes were able to answer questions about science process skills on the worksheet in the good category (Tables 5 and 6). The highest science process skills were obtained in the ability to identify variables, namely 89.25 in class V1 (Table 5) and 85.05 in class V2 (Table 6). In both class V1 and class V2, students are asked to identify independent variables, dependent variables and control variables. Almost 90% of students were able to answer that the color of the light, the power of the light, and the distance of the light in the OLabs virtual laboratory were the independent variables, while the dependent variable is the number of bubbles, and the control variables are the number and length of Hydrilla sp. Likewise, in class V2, light intensity and water temperature can serve as independent variables, while the dependent and control variables are the same as in class V1. This is in accordance with the research results by Nasution et al. (2025) that light intensity affects the speed of photosynthesis. The ability to identify variables is one of the science process skills that is considered to be the least mastered by students, it is considered to be one of the important things to pay attention to and improve (Fugarasti et al., 2019), this has been done in this study.

Based on the results of this study, it is very likely that, by carrying out this practical activity, students' process skills will increase from the pre-test to the post-test. The results of the parametric test of the data on the process skills of students in classes V1 and V2 have an Asymp. Sig. (2-tailed) value > 0.05, so there is no significant difference in science process skills between students in classes V1 and V2. Likewise, between students in classes L1 and V1, and in classes L1 and V2, there was no significant difference on both the pretest and posttest. Thus, it can be said that statistically comparatively, practical work using local materials and virtual materials provides equivalent effectiveness in achieving students' science process skills.

Based on the N-Gain values, the average category for student process skill improvement is medium. When viewed from the perspective of changes in students' process skills, the average is in the complementation category (Table 7), which means students can integrate new skills with initial skills into comprehensive skills. This is marked by a change from the moderate category to good. The science process skills students possess support scientific thinking and further abilities. One important aspect of developing students' process skills is that it can improve students' critical

DOI: https://doi.org/10.17509/aijbe.v9i1.97369
e-ISSN 2621-7260

thinking (Astalini et al., 2023; Choirunnisa et al., 2018; Harizon et al., 2024). Therefore, the science process skills of students who have reached the good and very good categories serve as the initial capital for achieving higher-level thinking skills in the future.

Table 7
Average category of changes in students' science process skills.

Science Process Skills Indicator	Science Process Skills Change Category		
	L1	V1	V2
1. Differentiating	Complementation	Complementation	Complementation
2. Identifying Variables	Construction	Complementation	Construction
3. Predicting	Complementation	Revision	Revision
4. Formulating Hypothesis	Complementation	Revision	Construction
5. Communicating	Complementation	Complementation	Complementation
6. Interpreting	Complementation	Complementation	Complementation
Average	Complementation	Complementation	Complementation

Even though they use simple and easily obtained tools and materials, in class L1 students can carry out the Ingenhouz and Sachs photosynthesis practical activity completely, so that they can fill in all the science process skills questions on the worksheet with an average category of very good (Table 4). Thus, this shows that implementing the photosynthesis practical activity does not always require standard laboratory materials and equipment. By using local materials, students can carry out a practical activity that effectively trains their science process skills.

If there is an emergency situation, such as limited resources in the form of practical tools and materials, inadequate laboratory space, or a lack of time allocated for practical activities, as expressed by Rosdianti & Paidi (2021), then the practical activity can be done virtually. This study shows that the photosynthesis practical activity using the OLabs virtual laboratory and the Melati virtual laboratory can train several types of science process skills among students in the average good category (Table 5; Table 6). This is consistent with the research findings of Aripin & Suryaningsih (2021) and Rosdianti & Paidi (2021), which indicate that the implementation of virtual laboratories can improve students' science process skills. In practice, Android-based virtual laboratories offer many benefits, such as reducing laboratory infrastructure costs, providing protection from hazardous substances and materials, and enabling use over wider distances and spaces.

Another advantage of using this virtual laboratories is that it is economical in terms of materials and practical tools, and is practical for students to use both in the classroom learning process and independent learning, improve understanding because it can be repeated if we don't understand, time effective in carrying out experiments, and safe to carry out because of minimal occupational health and safety (Rosdianti & Paidi, 2021). However, because the virtual laboratories in this study were systematic, several limitations were found, including the type of independent variables being limited; likewise, the type of dependent variable has been determined. This opens opportunities for developers and teachers to innovate, enabling them to develop as many students' science process skills as possible.

Disadvantages of virtual laboratories, according to Rosdianti & Paidi (2021), include that students cannot directly carry out practical activities in the laboratory, so they don't provide real experience; not all computers can be used; and students cannot develop hands-on skills. Although it cannot develop hands-on skills, virtual laboratories can improve minds-on skills.

Although the results of this study show that students' science process skills are in the very good category, the science process skills are still basic and do not yet include integrated science process skills. To improve and develop as many aspects of students' science process skills as possible, other efforts may be needed besides carrying out practical activity and worksheets, for

DOI: https://doi.org/10.17509/aijbe.v9i1.97369
e-ISSN 2621-7260

example, by developing research-based worksheets (Thahir et al., 2021). By conducting mini-research, more types of students' science process skills can be developed. This is in line with the research results of Berlian et al. (2023), which indicates that research-based learning is highly effective in improving students' science process skills. Venturas et al. (2024) have successfully developed and used PHYSIOGAM is an educational innovation project based on gamification and information and communication technologies (ICTs). The simulator can help students to experimentally test how plants open and close their stomata to regulate water loss and photosynthetic assimilation. Thus, it is likely that many more concepts and science process skills can be learned. The research of Agustina & Rahmat (2020) on learning through Schoology in physiology practicums, namely, a website that combines e-learning and social networks. During learning, students can easily understand practical material and how it works by viewing it in the form of modules, videos, or PowerPoint presentations. Recommendations from various research results regarding the development of various aspects of science process skills in this research it seems that the practical activity carried out must start to move towards inquiry-based practical activity and use post-laboratory activities. As stated by Lati et al. (2012) and Derilo (2019), the curriculum should emphasize science process skills and provide opportunities for inquiry-based learning, guided inquiry, and digital applications to enhance students' science process skills (Anjugam & Chellamani, 2022). Apart from that, to make it easier to carry out practical activities, there needs to be a module that includes worksheets, complete with videos and/or PowerPoint presentations. The uploaded videos can be interactive, so the gamification aspect appears and can enrich the observation variables. Furthermore, Rayment et al. (2023) stated that scaffolding for post-laboratory activities can provide bioscience students with greater integration between practical and theoretical understanding, resulting in more meaningful laboratory learning. Therefore, post-laboratory follow-up needs to be further strengthened by teachers.

The students' acquisition of science process skills was most likely due to the scaffolding effect resulting from the highly relevant worksheet questions. According to Maison et al. (2020) apart from being influenced by the type of practical activity guidelines used, the mastery of science process skills is also influenced by the infrastructure to support practical activities, students 'initial knowledge and mastery of students' initial science process skills. Apart from that, the value of students' science process skills is influenced by factors such as learning methods, learning media, practical activities, and methods of assessment or evaluation (Akbar et al., 2023). Factors of infrastructure facilities are the completeness of laboratory equipment, the state of the laboratory room, and the completeness of books in the library. Some experts say that the existence of science process skills in textbooks is important in supporting students' science process skills (Özalp, 2023; Sideri & Skoumios, 2021). This infrastructure factor is slightly refuted by the presence of a virtual laboratory in this study.

Contribution of Practical Activity to Students' Digital Literacy

The following is data about the average digital literacy score of class V1 and Class V2 students as shown in Table 8. From Table 8, it can be seen that the average digital literacy of students before the practical activity was carried out was relatively low, namely 43.23 for class V1 and 51.72 for class V2. The lowest (very low) aspect of digital literacy of class V1 students in the pretest was functional skills and beyond, and critical thinking and evaluation. In this study, the functional skill and beyond components that were trained were the ability to use digital devices to access virtual laboratories and the ability to use virtual laboratories to access information. In this indicator, students are asked to sequence the stages for searching for a virtual laboratory on a browser, namely connecting to the internet network, open a web browser, type keywords in the address bar, select a virtual laboratory from the search results and assess the suitability of the laboratory you wish to use. Because it is still early, most students are still confused about how to operate it, so their scores are still very low. Likewise, in the critical thinking and evaluation indicator, students

DOI: https://doi.org/10.17509/aijbe.v9i1.97369
e-ISSN 2621-7260

are asked to select information on search engines that does not match their needs. Students are still not focused on important information that must be obtained immediately.

Table 8

Average digital literacy score of class V1 and class V2 students.

Digital Literacy Indicator		Pretest Score of Digital Literacy		Posttest Score of Digital Literacy		N-Gain	
		V1	V2	V1	V2	V1	V2
1.	Functional skill and beyond	30.64 (Very Low)	50.00 (Low)	85.48 (Very Good)	86.21 (Very Good)	0.80 (High)	0.76 (High)
2.	The ability to find and select information	40.32 (Low)	46.55 (Low)	69.35 (Moderate)	70.69 (Good)	0.54 (Medium)	0.42 (Medium)
3.	Cultural and social understanding	66.13 (Moderate)	70.69 (Good)	93.55 (Very Good)	94.83 (Very Good)	0.82 (High)	0.83 (High)
4.	Critical thinking and evaluation	32.26 (Very Low)	48.28 (Low)	51.61 (Low)	68.97 (Moderate)	0.30 (Medium)	0.37 (Medium)
5.	Collaboration	46.77 (Low)	43.10 (Low)	61.29 (Moderate)	67.24 (Moderate)	0.20 (Low)	0.32 (Medium)
Average		43.23 (Low)	51.72 (Low)	72.26 (Good)	77.59 (Good)	0.54 (Medium)	0.59 (Medium)

After conducting practical activity using the OLabs virtual laboratory and the Melati virtual laboratory, students' digital literacy increased to a good average. The best category (very good) is found in the functional skills and beyond aspects, as well as in cultural and social understanding. It is likely that students really enjoy and learn quickly so that they are much more skilled than before. Thus, it is not surprising that the N-gain for these two digital literacy indicators falls into the high category. This also happens among undergraduate students (Agustin & Krismayani, 2019; Br Ginting & Magistra, 2024; Dinata, 2021; Syabaruddin & Imamudin, 2022; Yanti et al., 2021), elementary school teacher (Fauziah et al., 2023) and high school students (Nugroho & Nasionalita, 2020), even middle school students (Anggia et al., 2022; Paujiah et al., 2024) and elementary school (Kailani et al., 2021; Nafisah et al., 2023). In the aspect of cultural and social understanding, students are required to understand the icons on search engines and icons in virtual laboratories., for example, pressing the icon on the browser that can be used to return to the previous page on the search engine, namely back.

Even though the average digital literacy of students has reached a good level, aspects such as critical thinking and evaluation remain low. It seems that students do not fully understand how to identify the most important information needed, as required in critical thinking and evaluation questions. In this question, students are asked to find sources of information about the importance of light for photosynthesis, which will be used to support the results of the virtual laboratory implementation. Only about 60% of students were able to answer it correctly, that the button that should be pressed is the resource, not the procedure or animation. Evaluating content obtained from the internet is a digital literacy competency that is more important than simply searching for information (Akbar & Anggraeni, 2017). Critical thinking skills in digital literacy are very important, because of the large amount of information available in the media, policies are needed to filter information in the environment, while taking control over the information provided by the media, which is also called media literacy (Naufal, 2021; Restianty, 2018).

DOI: https://doi.org/10.17509/aijbe.v9i1.97369
e-ISSN 2621-7260

Another aspect of digital literacy that needs improvement is collaboration, with an N-gain value of 0.20 (Table 8). In this aspect, students are required to be able to build ideas together in an online community. There are still around 60% of students who can determine the most appropriate method when different ideas emerge in a group from each group member, in order to build ideas together, it is necessary to allow each member to put forward ideas in turn. The pretest and posttest data of students' digital literacy were tested non-parametrically (Wilcoxon signed rank mean difference test) had an Asymp. Sig. (2-tailed) value > 0.05, indicating no significant difference in digital literacy skills between classes V1 and V2 students. So, it can be said that, statistically and comparatively, practical work using the OLabs virtual laboratory and the Melati virtual laboratory provides equivalent effectiveness in achieving students' digital literacy.

Table 9

Average category of changes in students' digital literacy.

Digital Literacy Indicator	**Digital Literacy Change Category**	
	V1	**V2**
1. Functional skill and beyond	Construction	Revision
2. The ability to find and select information	Revision	Revision
3. Cultural and social understanding	Complementation	Complementation
4. Critical thinking and evaluation	Construction	Revision
5. Collaboration	Revision	Revision
Average	Revision	Revision

Based on changes in digital literacy skills, the average in the revision category for both classes V1 and V2 (Table 9) indicates that students are able to improve their digital literacy competency from the low category to the good category. To improve students' digital literacy, the use of virtual laboratories can be an appropriate learning alternative. As (Payton & Hague, 2010) said, students who extensively and intensively use technology tend to easily adopt learning strategies using various technological tools to support the learning process. Even Akbar & Anggraeni, (2017); Kailani et al. (2021) and Salma et al. (2025) proposed that digital literacy competencies be included in the learning curriculum, considering that there are many benefits to be gained through digital literacy. It is said that digital literacy has a big impact on improving teacher professionalism (Naufal, 2021). However, it is also necessary to pay attention to the existence of digital divide barriers in the Indonesian context Kusumawati et al. (2021) and it is very necessary to support digital literacy in families and society to create harmony and filters against deviations in the use of digital media (Nugraha, 2022; Suriani & Hadi, 2022).

CONCLUSION

This study aimed to examine the effect of implementing photosynthesis practical activity using local materials and virtual laboratories on students' science process skills and digital literacy in plant physiology learning. The findings demonstrate that this integrated practical approach effectively improved both competencies. Students' science process skills advanced from the moderate to the good category at a medium N-gain level, with overall changes occurring at the complementation stage, indicating that students were able to integrate newly acquired skills with their prior knowledge into comprehensive, functional competencies. Similarly, digital literacy improved from the low to the good category at a medium N-gain level, with meaningful progress across multiple aspects, including functional skills, information seeking and selection, cultural and social understanding, critical thinking and evaluation, and collaboration, reflecting students' capacity to substantially revise and elevate their digital competency. These results suggest that

DOI: https://doi.org/10.17509/aijbe.v9i1.97369
e-ISSN 2621-7260

combining hands-on local material-based practicals with virtual laboratory experiences provides a meaningful and accessible learning environment that simultaneously supports scientific inquiry and digital skill development two competencies increasingly demanded in 21st-century science education. Nevertheless, this study was conducted within a single institutional context, which limits the generalizability of the findings to broader student populations or different learning settings. Future research should explore implementing inquiry-based approaches using interactive video-equipped worksheets to further deepen science process skills and examine the role of school-community-family collaboration in sustaining responsible and critical digital media use among students.

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Acknowledgment

Researcher would like to thank the university which funded this research and the participants who were involved in this research.

Authors' Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

How to Cite this Article

Diana, S., Firdaus, F., & Husna, Y. A. (2026). Contribution of practical activities to students' science process skills and digital literacy about photosynthesis. *Assimilation: Indonesian Journal of Biology Education*, *9*(1), 55-72. https://doi.org/10.17509/aijbe.v9i1.97369