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Process Oriented Guided Inquiry Learning (POGIL): Its Effectiveness in Increasing Students' Scientific Literacy Skills in Plant Physiology Course

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Abstract

Background: Today, the main goal of science learning is to create a scientifically literate society by understanding mathematics, physics, chemistry, biology, and technology. Therefore, this research aims to determine the effectiveness of the process-oriented guided inquiry learning (POGIL) model in improving students' scientific literacy skills in a Plant Physiology course. **Methods:** This study was a quasi-experiment using a control group pre-test and post-test design with 32 students as research subjects. Data collection techniques used tests, and research data were analysed using a one-way ANCOVA statistical test. **Results:** The results showed a significant difference in scientific literacy skills between the control and experimental classes by controlling for students' initial scientific literacy [$F(1,61) = 1977.228$, $p < 0.001$], effect size np2 = 0.97. **Conclusions:** Therefore, the POGIL model is highly effective in increasing students' scientific literacy skills in the Plant Physiology Course.

Keywords: Process Oriented Guided Inquiry Learning (POGIL); Scientific literacy; Quasi-experiment; Plant physiology

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Introduction

The primary objective of science learning today is to realise a society that is intelligent with science through understanding mathematics, physics, chemistry, biology, and technology (Norris et al., 2014). The importance of the existence of a scientific society is that everyone is required to participate in solving real-world problems, such as food availability, environmental pollution, climate change, natural disasters, and disease outbreaks (Astriawati & Djukri, 2019; Fortus et al., 2022). This makes it a unique challenge for higher education institutions to continue to train their undergraduate students' scientific literacy skills so that they can fully absorb and participate in modern society through various learning programs.

Scientific literacy is a term used to describe an understanding of science and its societal applications (Ogunkola, 2013; Norris et al., 2014; Costa et al., 2021). This skill is evaluated internationally by the Organization for Economic Cooperation and Development (OECD) through the Programme for International Student Assessment (PISA) every three years. The PISA results indicate that Indonesia was still below the average score of the OCDE for the four evaluation periods in 2012, 2015, 2018, and 2022 (OECD, 2014; OECD, 2017; OECD, 2019; OECD, 2023). These rankings resulted in Indonesia being categorised as a country with low scientific literacy. It is in line with several previous studies reported that the scientific literacy skills of undergraduate students in Indonesia are still in the low category (Novitasari, 2018; Adhani et al., 2020; Limiansih & Susanti, 2021).

A low level of scientific literacy has also been observed among biology education students at Bengkulu University, particularly in plant physiology courses. The observations made during plant physiology lectures indicate that students find it challenging to connect the observed plant physiology phenomena with the underlying concepts. Additionally, these undergraduate students struggled with devising and executing appropriate observation procedures, presenting their findings in an informative manner via tables or graphs, and conducting comprehensive analyses of their experimental results. These findings indicate that their scientific literacy skills are lacking. Meanwhile, the plant physiology course includes theoretical knowledge of the physiological processes occurring within the plant body and the practical application of these processes to maintain plant life. This subject is closely intertwined with everyday phenomena, particularly in the agricultural and plantation sectors. The study of plant physiology is essential in addressing the challenges of providing food and shelter in the global era, where agricultural land is becoming increasingly scarce owing to the conversion of land for residential and other purposes, and climate change is causing environmental stress that adversely affects agricultural output and food availability. Therefore, mastery of plant physiology is essential for science graduates to find solutions while developing scientific literacy.

The low level of scientific literacy among students is primarily attributed to inadequate opportunities provided during the learning process to develop process skills in both primary and higher education (Muhsam & Letasado, 2021; Ernawati et al., 2022). Learning typically involves memorising scientific concepts from books, with limited opportunities for hands-on applications or practical engagement with the subject matter (Fananta et al., 2017). As a result, the learning experience frequently remains superficial, with students merely memorising information without developing a deeper understanding or the ability to apply it in everyday life (Astriawati & Djukri, 2019). This situation renders science learning meaningless and contributes to low scientific literacy among undergraduate students. This is also exacerbated by the fact that some higher education practitioners do not realise that education has two components: content and process. Unfortunately, process components often receive insufficient attention. To improve students' science abilities, it is necessary to pay equal attention to the knowledge component, which is the content component, and develop skills to acquire, apply, and produce knowledge, which is the process component. This highlights the need for learning innovations focusing on the content and emphasising process skills in learning activities to develop students' scientific literacy.

Numerous studies have demonstrated the usefulness of inquiry-based learning in fostering curiosity (Mouromadhoni et al., 2019; Irdalisa et al., 2021), investigative skills (Panjaitan & Siagian, 2020; Suantara et al., 2022), analytical thinking (Talakua & Sahureka, 2021), critical thinking (Malik et al., 2017; Dewi et al., 2021), and problem-solving skills (Lestari et al., 2019), which serve as foundations for scientific literacy. Despite this, the majority of inquiry-based learning is conducted in a guided (Hasanah et al., 2022; Suantara et al., 2022; Megawati, 2023) or accessible manner (Kholilurrohman & Suryadarma, 2019; Sari et al., 2022; Ernawati & Sari, 2022) and only focus on the content and outcomes of inquiry, while process-oriented Guided inquiry-based learning has not yet been implemented in science learning, especially at Bengkulu University. Process-oriented guided inquiry learning (POGIL) is an instructional strategy that combines guided inquiry and cooperative learning and includes three stages of learning: exploration, concept construction, and concept standards (Hanson, 2013; Brion et al., 2022). Researchers assumed that POGIL could provide students with opportunities to construct knowledge and develop process skills such as problem analysis, designing and conducting observations, presenting and interpreting data, processing information, critical thinking, problem-solving, and effective communication. According to the description, this study aimed to investigate the effectiveness of the process-oriented guided inquiry learning model in enhancing students' scientific literacy in a plant physiology course. It is imperative to conduct this research to provide valuable information to educational practitioners regarding applying the POGIL model to foster undergraduate students' scientific literacy, which is critical for success in a world that continues to evolve owing to science and technology.

Method

Research Design and Procedures

This study was a quasi-experiment with a non-equivalent pre-test and post-test control group design (Subali, 2019). The research design is shown in Table 1.

Table 1. Research Design

Class	Pre-test	Treatment	Post-test
Control	X1	P1	Y1
Experiment	X2	P2	Y2

Description:
P_1 = direct instruction
P_2 = POGIL
X_1= Pre-test in control class
X_2 = Pre-test in control class
Y_1 = Post-test in the experimental class
Y_2 = Post-test in the experimental class

This research entailed three primary phases: 1) an initial evaluation of scientific literacy skills in the control and experimental classes before treatment; 2) the administration of treatment through the implementation of the direct instruction learning model in the control class and the POGIL model in the experimental class consisting of stages such as problem orientation, exploration, conceptual formation, conceptual application, and evaluation; and 3) a final assessment of scientific literacy skills following the execution of treatment in the control and experimental classes.

Sample or Participant

The population in this study were students in the fourth semester of Biology Education, Faculty of Educational Sciences and Education, University of Bengkulu, who attended a plant physiology course in the 2022/2023 academic year. The sample selection of the research was based on the method of random cluster sampling, that is, by selecting two random learning groups (through voting) from three available learning groups, one as a control class and one as an experimental class.

Instrument

The data in this study are a student's scientific literacy score before (pre-test) and after (post-test) treatment in both the control and experimental classes. Data collection was performed using an essay test instrument. Scientific literacy test instruments are structured based on the PISA 2015 scientific literacy assessment indicator on the competence aspects of 1) explaining phenomena scientifically, 2) evaluating and designing scientific inquiry, and 3) interpreting data and evidence scientifically (OECD, 2019; Astriawati & Djukri, 2019). The instrument test in this study was valid and reliable based on expert assessment and test results using the Quest program (estimated reliability = 0.70; acceptance limits ≥ 0.77 to ≤1.30).

Data analysis

The students' scientific literacy score data were analyzed using a one-way ANCOVA test with SPSS software version 25. The assumptions that must be met in the one-way ANCOVA tests include 1) the dependent variable is a scale or ratio; 2) the independent variable is categorical data that divides the data into at least two unrelated groups; 3) observation independence; 4) no significant outlier; 5) normally distributed residual data; 6) variants of one group with another homogeneous group; 7) covariates must be linearly related to the bound variable; and 8) homogeneity of regression bending.

Furthermore, the improvement in students' science literacy was analysed based on the effect size value for the F test (Eta Squared). The value of the effect size obtained was interpreted based on the criteria in Table 2 to determine the level of improvement in students' scientific literacy (Becker, 2000; Ellis, 2010).

Table 2. Category of Effect Size for F Test

Eta Squared	Effect Size
0.01	Low
0.06	Medium
0.14	High

Result

Data on this study are pre-test and post-test scores of scientific literacy students in the control and experimental classes, as shown in Table 3.

Table 3. Students' Scientific Literacy Score in Plant Physiology Course

Description	Control Class		Experimental Class	
	Pre-test	Post-test	Pre-test	Post-test
Sample	32	32	32	32
Mean	35.23	65.66	35,78	84.49
Median	35.00	65.62	35.62	85.00
Standard Deviation	7.31	6.88	6.80	6.21
Minimum	21.25	51.25	20.00	71.25
Maximum	50.00	78.75	50.00	97.50

Based on Table 3, the research subjects amounted to 32 students in both the control and experimental classes. The pre-test score in the control class was 35.23, while that in the experimental class was 35.78. The post-test scores in the controlled class are 65.66, while the post-test scores in the experimental class are 84.49. The spread of scientific literacy scores in the control and experimental classes is presented in Figures 1 and 2, respectively.

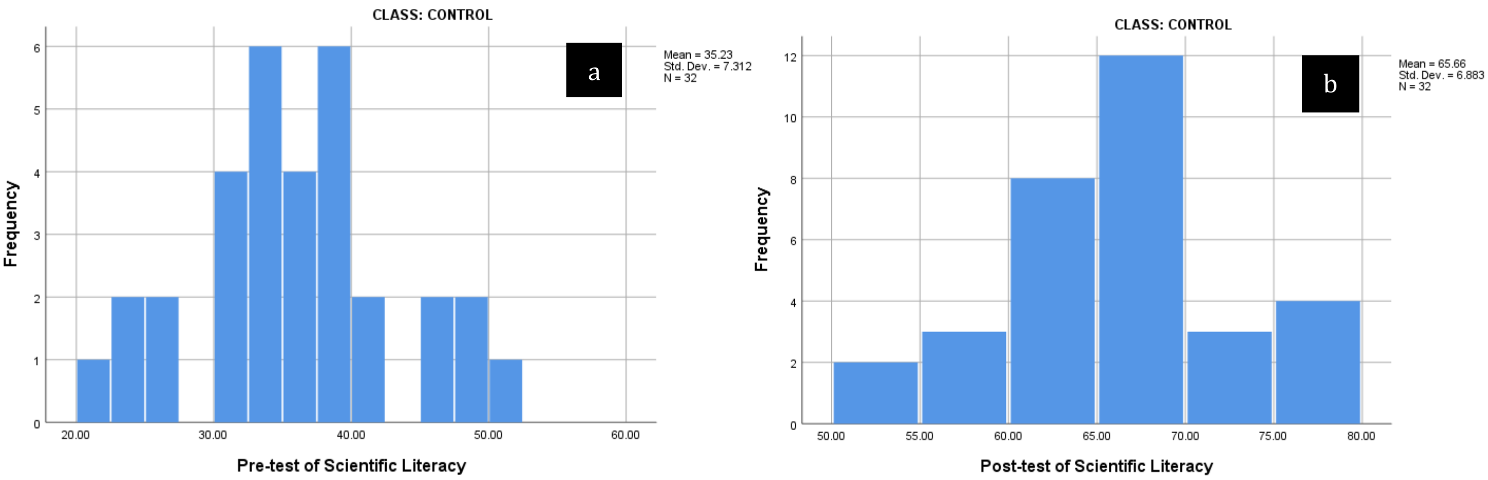

Figure 1. The spread of scores pre-test (a) and post-test of students' scientific literacy in the control class

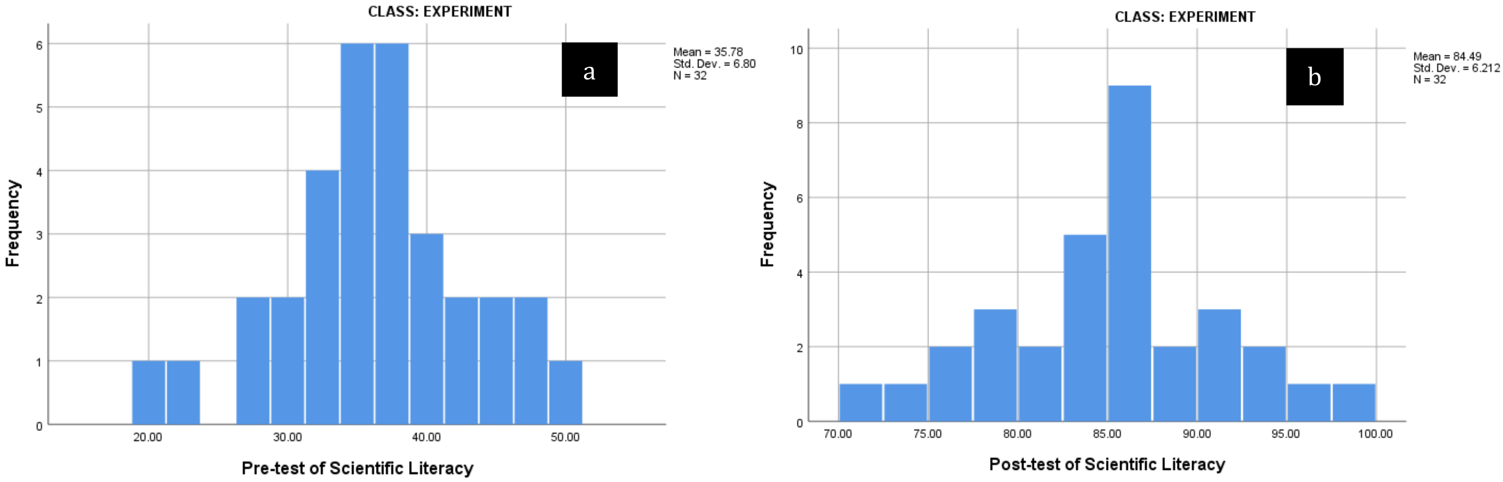

Figure 2. The spread of scores pre-test (a) and post-test of students' scientific literacy in experimental class

Before testing the hypothesis, the one-way ANCOVA test assumption was fulfilled. The dependent variable in this study was interval data (scientific literacy score), and the independent variables were nominal/category data (control and experimental classes). In addition, the study was conducted independently of observations, and no very low or very high scientific literacy scores were found among the students. Therefore, the first, second, third, and fourth assumptions were fulfilled. The fifth assumption is that the residual normality of the dependent variable is presented in Table 4.

Table 4. The result of the Normality Test of Residual Data

Data	Kolmogorov-Smirnov			Explanation
	Statistic	df	Sig	
Residual Data of Scientific Literacy	0.074	64	0.200	Normally

The results of the Kolmogorov-Smirnov test in Table 4 indicate that the residual distributed scientific literacy data are standard [D (64) = 0.074, p = 0.200], so the assumption of the fifth one-way ANCOVA test is fulfilled. The subsequent fulfilment of this assumption is the homogeneity of the data presented in Table 5.

Table 5. The result of the Homogeneity Test

Data	Levene's Test				Explanation
	F	df1	df2	Sig	
Scientific Literacy Score	3.060	1	62	0.085	Homogeneous

The results of Levene's test in Table 6 indicate that the variance of scientific literacy data between one class and another is homogeneous (F (1,62) = 3.060, p = 0.085]; thus, the assumption of the sixth one-way ANCOVA test is fulfilled. The following assumption is the linearity between the covariates and the dependent variable, as shown in Figure 3.

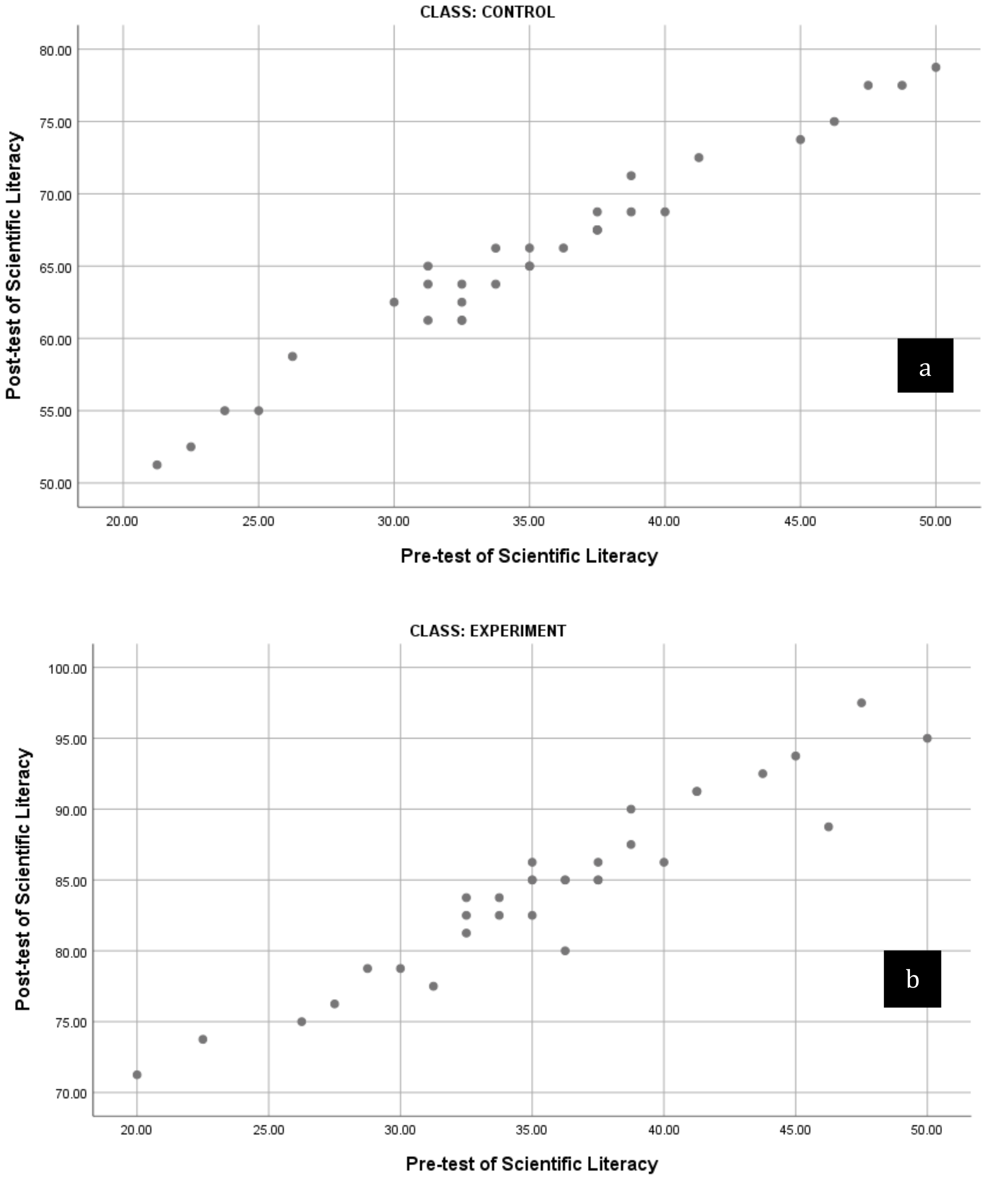

Figure 3. Linearity between covariates and dependent variables in a) control class and b) experimental class

The scatter plot in Figure 3 shows that the pre-test data (covariate) are linear to the scientific literacy post-test data (dependent variable), so the assumptions of the seventh one-way ANCOVA test are met. The following assumption is the homogeneity of the regression slopes in the two classes, as shown in Table 6.

Table 6. The result of the regression slope Homogeneity Test

Description	Test of Between-Subject Effect					Explanation
	Type III Sum of Squares	df	Mean Square	F	Sig.	
Class*Pre-test Scientific Literacy	2.470	1	2.470	0.908	0.345	Homogenous
Error	163.246	60	2.721			

The results in Table 6 indicate that the regression slope of pre-test data with post-test data on scientific literacy between one class and another is homogeneous [F (1,60) = 0.908, p = 0.345], so the assumptions of the eighth one-way ANCOVA test are fulfilled. As all assumptions have been met, scientific literacy data can be analysed using a one-way ANCOVA test.

Table 7. The result of The One-Way ANCOVA Test

Description	Test of Between-Subject Effect						Explanation
	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	
Class	5371.432	1	5371.432	1977.228	<0.001	0.97	High Influence
Error	165.716	61	2.717				

The results in Table 7 show that there was a significant difference in scientific literacy between the control and experimental classes by controlling for students' initial scientific literacy skills [*F* (1,61) = 1977.228, p < 0.001, np^2 = 0.97]. These results also indicate that applying the POGIL model is practical in improving students' scientific literacy skills based on the effect size value obtained (eta squared = 0.97).

Increasing students' scientific literacy skills occurs for each indicator, namely explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically. A comparison of the achievements of the scientific literacy skills indicators between the control and experimental classes is presented in Figure 4.

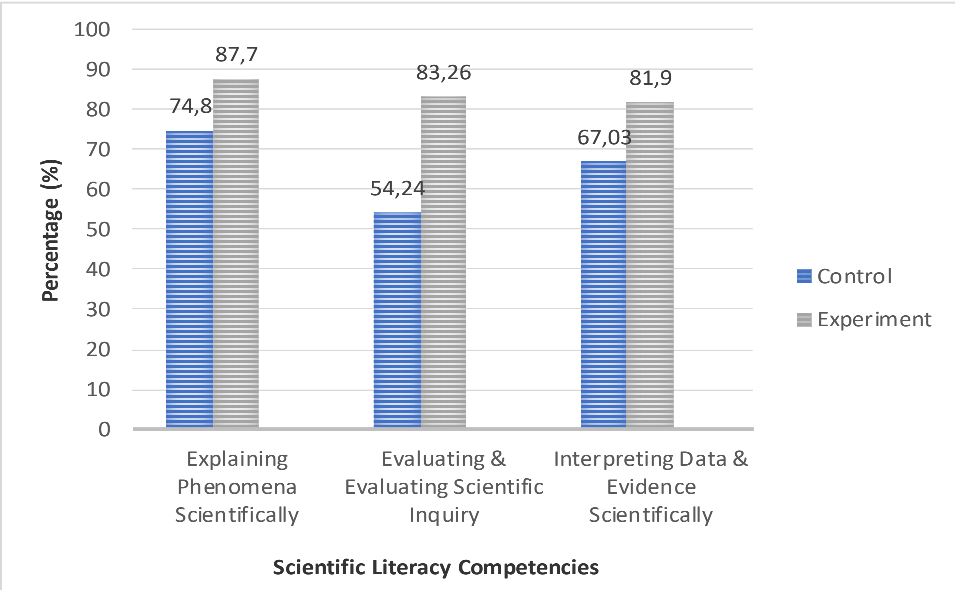

Figure 4. The Achievement of scientific literacy skills for each indicator in the control and experimental classes.

The graph in Figure 4 shows differences in the achievements of each indicator of student scientific literacy between the control and experimental classes. In the control class, the indicator achievement of explaining phenomena scientifically was 74.8%, evaluating and designing scientific inquiry was 54.24%, and interpreting data and evidence scientifically was 67.03%. Meanwhile, in the experimental class, the indicator achievement of explaining phenomena scientifically was 80.24%, evaluating and designing scientific inquiry was 82.95%, and interpreting data and evidence scientifically was 81.82%; thus, it is clear that the Achievement of each scientific literacy indicator in the experimental class was higher than in the control class. Based on this description, it can be concluded that applying the process-oriented guided inquiry learning (POGIL) model effectively increases students' scientific literacy in Plant Physiology courses.

Discussion

Learning in higher education refers to an outcome-based education (OBE) curriculum. The curriculum emphasises student learning outcomes to support college graduates. One of the essential learning outcomes for students to master is scientific literacy skills, which help students face the challenges of the 21st century, which are filled with uncertainty, and everything is influenced by science and technology. In this regard, this research examines the effectiveness of process-oriented guided inquiry learning (POGIL) on students' scientific literacy skills in the plant physiology course as an effort to improve the quality of learning in higher education.

The research findings indicate that implementing the Process Oriented Guided Inquiry Learning (POGIL) model is highly effective in enhancing students' scientific literacy skills, consistent with several previous studies that examined similar learning designs. Several studies, such as Daniah (2020), have highlighted that inquiry-based learning involves students actively participating in the learning process by posing questions, conducting investigations, and searching for information, increasing students' curiosity about the topics and problems being studied. Jaya et al. (2022) also have reported that through inquiry learning, students become more sensitive to scientific issues, examine them more deeply, and attempt to find scientific solutions. Additionally, process-oriented inquiry-based learning can train students in investigative skills, such as identifying problems, designing observations, exploring and collecting data, interpreting data, and communicating results (Fitria & Hidayah, 2021; Yani & Hikmah, 2023). Improving the skill achievements described contributes to developing the competencies of scientific literacy skills.

Scientific literacy skills are individuals' capacity to engage in scientific issues and ideas to express citizenship. A scientifically literate person can participate in rational discussions about science and technology, which necessitates the acquisition of competencies, such as the ability to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically (OECD, 2017; Astriawati & Djukri, 2019). The ability to explain phenomena scientifically involves identifying, providing, and evaluating explanations related to scientific and technological issues based on scientific evidence. Assessing and designing scientific inquiry entails performing scientific procedures and ensuring their suitability for addressing questions or justifying claims about scientific problems. Interpreting data and scientific evidence involves representing research data in 3D visualisation and then analysing and evaluating patterns, which are the basis for drawing evidence-based conclusions on scientific issues.

Implementing the POGIL model in plant physiology lectures can lead to developing scientific literacy competencies, as described. POGIL is a learning model that integrates guided inquiry learning and cooperative learning and consists of three main stages of learning: exploration, concept construction, and concept application (Hanson, 2013; Brion et al., 2023). By utilising this model, students are encouraged to actively engage with scientific issues and phenomena in the plant world by seeking relevant theories and testing them through scientific inquiry processes such as exploration, investigation, or experimentation. Students then represent their findings in tables, graphs, or diagrams and carry out analysis and evaluation as a basis for argument claims or decision-making regarding the studied issues. Through this process, students construct knowledge and develop cognitive skills, such as interpreting scientific data, analytical and critical thinking, problem-solving, and communicating effectively based on cooperative learning. This aligns with previous research, which states that inquiry-based learning involves actively engaging students in the learning process by asking questions, investigating, and finding information (Fitri & Fatisa, 2019; Aprizanti, 2023). By engaging in inquiry-based learning, students develop analytical thinking (Ramadani et al., 2021), critical thinking (Wale & Bishaw, 2020; Maharani et al., 2023), and communication skills (Fatkhriyah, 2019; Apriyani et al., 2022).

Furthermore, applying the POGIL model to the Plant Physiology course directs students to work in small groups to solve problems and answer questions about scientific phenomena in the plant world. Problem-solving involves collecting scientific evidence through observation, exploration, and investigation activities. The data obtained from the investigation were then processed and interpreted as answers to the questions asked. Therefore, indirectly, the POGIL model syntax trains each competency of scientific literacy:

explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically. This is to previous research, which states that the application of the POGIL model is practical in increasing students' problem-solving (Divrik et al., 2020; Pujiani, 2022) and scientific process skills (Syahgiah, 2023; Biswal & Behera, 2023).

Researchers have identified several benefits of implementing the POGIL model in plant physiology. Firstly, POGIL promotes active learning, involving students actively engaging in learning instead of passively receiving information. This approach has resulted in better information retention and a deeper understanding of the material. Secondly, POGIL requires students to work in small groups to solve problems and answer questions, developing their teamwork and communication skills while learning from their peers. Thirdly, POGIL is based on the inquiry learning model, which emphasises student involvement in the inquiry process, including asking questions, making observations, conducting experiments, and drawing conclusions based on evidence. This approach has been supported by previous studies, which found that the inquiry learning model enhances student learning activities (Utami & Sundari, 2019; Rumain & Geliebter, 2020), promotes in-depth understanding of concepts (Utami & Sundari, 2019; Syarifudin, 2023), encourages investigative skills (Mulyeni et al., 2019; Panjaitan & Siagian, 2020) and fosters collaboration (Anjani et al., 2018; Rumain & Geliebter, 2020).

The POGIL learning model offers a distinct advantage in that it facilitates the development of crucial process skills, including scientific inquiry, analytical and critical thinking, problem-solving, and scientific argumentation, which ultimately enhance students' scientific literacy skills. These skills are highly beneficial both within the academic and professional spheres. Given the characteristics mentioned earlier, it is evident that the POGIL learning model has demonstrated high effectiveness in elevating students' scientific literacy and academic performance compared to traditional lecture-based teaching methods, also known as direct instruction.

Conclusions

This study investigated the efficacy of process-oriented guided inquiry learning on students' scientific literacy. The findings indicate that the implementation of the process-oriented guided inquiry learning model is highly effective in enhancing students' scientific literacy, as evidenced by the one-way ANCOVA statistical test [$F(1,61) = 1977.228$, $p < 0.001$, np2 = 0.97]. The POGIL model encourages students to actively engage with scientific issues and phenomena by seeking relevant theories and testing them through scientific inquiry processes, such as exploration, investigation, or experimentation. Students then represent their findings in tables, graphs, or diagrams and conduct analysis and evaluation as a basis for argument claims or decision-making regarding the studied issues. This research suggests that the POGIL model is a relevant alternative learning model for the 21st century, influenced by science and technology. Additional research is needed to assess the applicability of the POGIL model to other skills and to uncover further positive outcomes associated with the model.

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