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Differential Improvement of Scientific Literacy Indicators through Citizen Science Project-Based Learning in Higher Education

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ABSTRAK

Penelitian ini bertujuan menganalisis peningkatan diferensial pada setiap indikator literasi sains mahasiswa setelah penerapan model pembelajaran *Citizen Science Project* di pendidikan tinggi. Penelitian menggunakan pendekatan kuantitatif dengan desain satu kelompok pretest-posttest. Subjek penelitian terdiri atas 40 mahasiswa program studi Keselamatan dan Kesehatan Kerja yang menempuh mata kuliah Anatomi dan Fisiologi Manusia. Instrumen penelitian berupa tes literasi sains berbasis delapan indikator yang mencakup identifikasi argumen ilmiah, evaluasi informasi ilmiah, pemahaman desain penelitian, representasi dan interpretasi data, keterampilan kuantitatif, statistik dasar, serta inferensi berbasis bukti. Data dianalisis secara deskriptif untuk mengidentifikasi pola peningkatan pada setiap indikator. Hasil penelitian menunjukkan bahwa rerata skor literasi sains meningkat dari 51,72 pada pretest menjadi 82,81 pada posttest. Peningkatan tertinggi terjadi pada indikator memahami dan menafsirkan statistik dasar (98,36%), diikuti inferensi berbasis data kuantitatif (80,52%) dan interpretasi grafik (80,26%). Indikator evaluasi penggunaan dan penyalahgunaan informasi ilmiah menunjukkan peningkatan paling rendah (32,08%). Temuan ini menunjukkan bahwa model pembelajaran *Citizen Science Project* efektif dalam memperkuat dimensi literasi sains berbasis data dan penalaran kuantitatif, dengan pola peningkatan yang berbeda pada setiap indikator.

Kata Kunci: citizen science project, literasi sains, pendidikan tinggi, peningkatan diferensial, pembelajaran berbasis proyek

ABSTRACT

This study aimed to analyze the differential improvement of each scientific literacy indicator among university students following the implementation of the Citizen Science Project learning model in higher education. A quantitative approach employing a one-group pretest-posttest design was used. The participants consisted of 40 students enrolled in the Occupational Health and Safety program who were taking the Human Anatomy and Physiology course. The research instrument was a scientific literacy test based on eight indicators, including identification of scientific arguments, evaluation of scientific information, understanding of research design, data representation and interpretation, quantitative problem-solving skills, basic statistical reasoning, and evidence-based inference. Data were analyzed descriptively to examine patterns of improvement across indicators. The results showed that the mean scientific literacy score increased from 51.72 on the pretest to 82.81 on the posttest. The highest improvement was observed in understanding and interpreting basic statistics (98.36%), followed by evidence-based inference (80.52%) and graphical data interpretation (80.26%). In contrast, the lowest improvement occurred in evaluating the use and misuse of scientific information (32.08%). These findings indicate that the Citizen Science Project learning model is effective in strengthening the data-driven and



quantitative dimensions of scientific literacy, although the level of improvement varies across indicators.

Keywords: *citizen science project, differential improvement, higher education, project based learning, scientific literacy*

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INTRODUCTION

Scientific literacy constitutes an essential competence in twenty-first-century higher education, as it plays a pivotal role in shaping students' capacity to understand, evaluate, and responsibly apply scientific knowledge. Scientific literacy extends beyond the mere mastery of disciplinary concepts; it encompasses the ability to interpret data, critically assess scientific arguments, comprehend research design, and make evidence-based decisions (Aristeidou et al., 2020; Hartono, Djulia et al., 2023). The demand for scientific literacy has intensified in response to the growing complexity of environmental, health, and social challenges, which require scientifically informed reasoning in both professional practice and civic engagement (Klemenčič et al., 2023). Higher education institutions therefore hold a strategic responsibility in preparing graduates who are capable of participating critically and constructively in knowledge-based societies.

Empirical findings over the past decade indicate that the level of university students' scientific literacy across various regions of Indonesia remains within the low to moderate range (Suwono et al., 2023; Suwono et al., 2017), particularly in aspects related to data analysis, interpretation of graphical representations, and evaluation of the validity of scientific information. These weaknesses suggest that existing instructional practices have not fully integrated authentic scientific practices into classroom activities. Instruction that predominantly emphasizes content delivery and information reproduction tends to provide limited opportunities for students to develop evidence-based argumentation skills and quantitative reasoning (Suwono et al. 2017). This condition reflects a gap between the competencies demanded in the twenty-first century and the prevailing practices of science instruction in higher education.

Numerous studies report that inquiry-based learning, problem-based learning, and project-based learning contribute to improvements in scientific literacy (Fan and Chen, 2019). Such improvements are generally measured through

comparisons of aggregate pretest and posttest scores. Although aggregate-score analyses provide an overall picture of intervention effectiveness, they offer limited insight into the developmental dynamics of individual scientific literacy indicators. Scientific literacy is inherently a multidimensional construct comprising distinct indicators, including identification of scientific arguments, evaluation of sources, quantitative data analysis, graphical representation, basic statistical interpretation, and evidence-based inference. Reliance solely on total scores risks oversimplifying the complexity of competence development and obscuring variations in how specific indicators respond to instructional interventions.

Recent literature underscores the importance of indicator-based analysis to obtain a more nuanced understanding of the mechanisms underlying improvements in scientific literacy. However, most previous studies investigating the effects of inquiry-based learning, problem-based learning, and project-based learning have relied primarily on aggregate pretest–posttest scores or overall scientific literacy indices (Markula and Aksela 2022). While such approaches are useful for determining general effectiveness, they do not reveal which specific dimensions of scientific literacy are most strongly influenced by instructional interventions. Consequently, important information regarding the differential development of competencies such as scientific argumentation, evaluation of information sources, quantitative reasoning, graphical interpretation, and statistical literacy remains largely unexplored. The lack of indicator-level investigations limits both theoretical understanding of scientific literacy as a multidimensional construct and the development of targeted pedagogical strategies aimed at strengthening specific literacy dimensions. Therefore, studies examining patterns of improvement across individual scientific literacy indicators remain necessary, particularly in higher education contexts where evidence is still limited.

Citizen Science Project (CSP) refers to an educational approach that actively involves students in authentic scientific investigations that contribute to broader scientific or community-related goals. In this approach, students participate in various stages of scientific inquiry, including problem identification, data collection, analysis, interpretation, and communication of findings, often addressing real-world environmental or societal issues (Bonney et al. 2016; Susiati et al. 2025). Unlike conventional project-based learning, CSP emphasizes meaningful participation in scientific practices that mirror the work of professional scientists

while simultaneously promoting civic engagement and community contribution. Consequently, CSP provides a potentially powerful context for fostering multiple dimensions of scientific literacy through authentic experiences with scientific evidence and decision-making.

The Citizen Science Project-based learning model offers an instructional framework that positions students as active participants in authentic scientific processes (Adnan et al., 2024; Susiati et al., 2025). Activities such as problem mapping, project design, investigation implementation, data analysis, and presentation of findings engage students directly in the collection and interpretation of empirical evidence. Theoretically, these activities have the potential to activate dimensions of scientific literacy related to data-driven reasoning and the evaluation of scientific arguments. Engagement in projects oriented toward real-world issues may also foster cognitive conflict, thereby supporting conceptual change and strengthening scientific knowledge structures.

Previous studies (Markula and Aksela, 2022; Webster et al., 2022) have reported that project-based learning and scientific participation can enhance students' scientific literacy in general. However, information regarding which specific indicators demonstrate the most significant gains and how such patterns of improvement emerge remains limited. This limitation underscores the need for research that explicitly examines scientific literacy development at the indicator level following the implementation of the Citizen Science Project model in higher education. A differential analysis of eight scientific literacy indicators will provide a more comprehensive account of the model's contribution to each dimension of students' scientific competence.

Based on the identified research gap, this study investigates the differential development of scientific literacy following the implementation of the Citizen Science Project-based learning model in higher education. Specifically, the study addresses the following research questions, RQ1: To what extent does the Citizen Science Project-based learning model improve students' overall scientific literacy?; RQ2: How do the eight scientific literacy indicators differ in their levels of improvement following the implementation of the Citizen Science Project-based learning model?; RQ3: Which scientific literacy indicators exhibit the highest and lowest gains, and what pedagogical interpretations can explain these variations?. By addressing these questions, the study contributes to a more detailed

understanding of scientific literacy development at the indicator level and provides evidence for designing instructional strategies that target specific dimensions of scientific competence.

METHODS

This study employed a quantitative approach using a one-group pretest-posttest design to examine the differential improvement of scientific literacy indicators following the implementation of the Citizen Science Project (CSP) learning model in higher education. The participants consisted of 40 students enrolled in the Occupational Safety and Health (OSH) program who were taking the Human Anatomy and Physiology course at Universitas Famika. A total sampling technique was employed, whereby all students enrolled in the course participated in the study. The intervention was conducted over one academic semester.

The Citizen Science Project learning model was implemented through five sequential stages: mapping, project design, presenting, execution, and gallery walk. During the mapping stage, students identified authentic health-related problems in their surrounding environment. In the project design stage, students formulated investigation plans and selected appropriate methods for data collection. The presenting stage involved proposal presentation and peer feedback. Subsequently, students conducted field investigations, collected empirical data, and analyzed findings during the execution stage. Finally, the gallery walk stage enabled students to communicate and defend their findings through evidence-based presentations. The instructional process was supported by a Learning Management System (LMS) that facilitated discussion forums, analytical quizzes, project monitoring, and assignment submission.

Data were collected using a Scientific Literacy Test (SLT) developed based on the scientific literacy framework proposed by (Gormally, Brickman, and Lutz 2012). The instrument consisted of 24 multiple-choice items distributed across eight scientific literacy indicators: (1) identification of scientific arguments, (2) evaluation of source validity, (3) understanding of research design, (4) quantitative data analysis, (5) graphical representation, (6) graph interpretation, (7) comprehension of basic statistics and quantitative skills, and (8) evidence-based inference. Each indicator was represented by three items. Each correct answer received one point, whereas incorrect answers received zero points, resulting in a maximum score of 24.

An example item required students to interpret a graph showing the relationship between physical activity and cardiovascular health and identify the conclusion most strongly supported by the data. Such items were designed to assess students' ability to analyze empirical evidence and make scientifically justified decisions in real-world contexts. Content validity was evaluated by three experts in biology education and science literacy assessment. The content validity index (CVI) exceeded the minimum acceptable threshold of 0.80, indicating satisfactory content validity. Instrument reliability was assessed using Cronbach's alpha coefficient, yielding a value of 0.82, which indicates good internal consistency.

Data collection was conducted through pretest administration before the implementation of the CSP model and posttest administration after all instructional stages had been completed. Descriptive statistics were calculated to determine mean scores and normalized gain (N-gain) values for overall scientific literacy and each indicator. Prior to inferential analysis, the normality of score distributions was examined using the Shapiro–Wilk test. Because the data met the assumption of normality, a paired-samples t-test was conducted to determine whether differences between pretest and posttest scores were statistically significant. The significance level was set at $\alpha = 0.05$. In addition, Cohen's d effect size was calculated to evaluate the magnitude of the observed improvements. Differential improvements among the eight scientific literacy indicators were analyzed using indicator-level N-gain scores and descriptive comparisons.

RESULTS AND DISCUSSION

A differential analysis was conducted across eight scientific literacy indicators to identify patterns of improvement in greater detail. A summary of pretest scores, posttest scores, and percentage gains is presented in Table 1.

Table 1. Improvement in Scientific Literacy by Indicator

No	Scientific Literacy Indicator	Pretest (%)	Posttest (%)	Improvement (%)
1	Identification of scientific arguments and evaluation of source validity	50,63	77,50	53,09
2	Evaluation of the use and misuse of scientific information	66,25	87,50	32,08

No	Scientific Literacy Indicator	Pretest (%)	Posttest (%)	Improvement (%)
3	Understanding elements of research design	50,63	86,25	70,37
4	Constructing graphical representations of data	53,75	78,13	45,35
5	Reading and interpreting graphs	47,50	85,63	80,26
6	Quantitative problem-solving	58,75	85,00	44,68
7	Understanding and interpreting basic statistics	38,13	75,63	98,36
8	Data-based inference and prediction	48,13	86,88	80,52

The table indicates that all indicators demonstrated improvement, albeit with varying levels of achievement. The indicator related to understanding and interpreting basic statistics exhibited the highest gain, reaching 98.36 percent. This finding suggests that data analysis activities during the execution phase and reflective discussions in the gallery walk stage contributed substantially to strengthening students' statistical literacy. Through direct engagement in reading, processing, and interpreting empirical data, students experienced reinforcement of the quantitative dimension of scientific literacy.

The indicators of reading and interpreting graphs, as well as drawing data-based inferences, also showed substantial increases of 80.26 percent and 80.52 percent, respectively. These results indicate that the scientific project-based learning model encouraged students to integrate visual representation and logical reasoning within the process of scientific decision-making. Activities such as problem mapping and research outcome analysis supported students in systematically linking data to conclusions.

The indicator concerning understanding elements of research design increased by 70.37 percent. This improvement suggests that students developed a clearer comprehension of the relationships among variables, methods, and scientific conclusions. Active involvement in project design prompted students to consider the structural components of research more deliberately, thereby strengthening the methodological dimension of scientific literacy.

In contrast, the indicator reflecting the evaluation of the use and misuse of scientific information demonstrated a relatively lower increase of 32.08 percent.

This outcome implies that evaluative skills related to identifying bias and misinterpretation require deeper and more sustained reflective practice. The evaluative dimension of scientific literacy involves complex metacognitive processes, and thus its development tends to be more gradual.

Table 2. Results Inferential Analyze in Scientific Literacy

Variable	Pretest Mean $\pm$ SD	Posttest Mean $\pm$ SD	t	p	Cohen's d
Scientific Literacy	51.72 $\pm$ 10.43	82.81 $\pm$ 8.27	12.45	<0.001	1.85

A paired-samples t-test revealed a statistically significant increase in students' scientific literacy scores, $t(39)=12.45$, $p<0.001$, with a large effect size ($d=1.85$). The observed pattern of differential improvement confirms the multidimensional nature of scientific literacy and indicates that responses to instructional interventions are not homogeneous across indicators. The Citizen Science Project learning model appears to be particularly effective in enhancing data-driven and statistical dimensions of scientific literacy. Variations in achievement across indicators provide important pedagogical insights for lecturers in designing more targeted follow-up interventions, especially to strengthen students' capacity to evaluate scientific arguments and the validity of information.

A visual comparison of scientific literacy scores before and after the implementation of the Citizen Science Project model is presented in Figure 1.

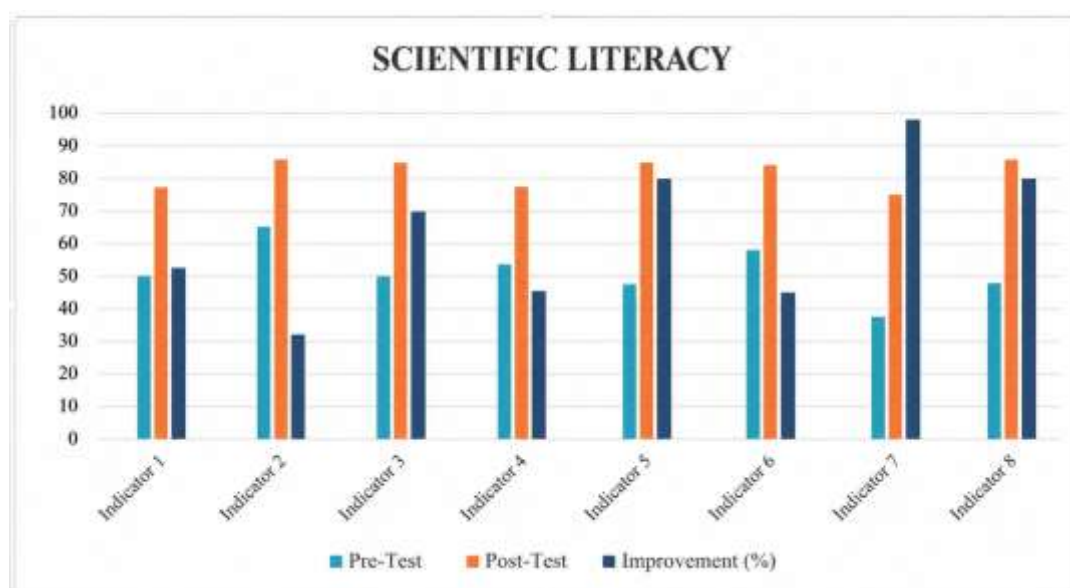


Figure 1. Description of Scientific Literacy Skills Across Indicators

This graphical representation is intended to clarify the comparative pattern of improvement across indicators and to provide a visual overview of the variations in achievement among them. These findings demonstrate that indicator-level analysis provides a more comprehensive understanding than reliance solely on aggregate total scores. A differential approach enables the identification of specific dimensions of scientific competence that are most responsive to participatory, science-based instructional designs. The contribution of this study lies in its detailed mapping of students' scientific literacy development, thereby offering a more precise foundation for the design and refinement of instructional strategies in higher education.

The substantial improvement observed across several scientific literacy indicators suggests that the Citizen Science Project learning model is effective in strengthening evidence-based scientific competencies, particularly in dimensions related to data analysis and interpretation. From a theoretical perspective, scientific literacy encompasses the ability to explain phenomena scientifically, evaluate and design scientific investigations, and interpret data and evidence scientifically, as articulated in the Programme for International Student Assessment (PISA) framework, which is internationally recognized as a benchmark for assessing these competencies (PISA, 2017).

As presented in Table 1, the indicator concerning understanding and interpreting basic statistics demonstrated the highest increase (98.36%). This finding aligns with contemporary scholarship emphasizing the central role of statistical skills and data interpretation in scientific literacy. McCarthy and Kuhlemeyer (2024) underscore statistical literacy as an integral component of holistic scientific literacy, encompassing the capacity to comprehend quantitative data and derive meaningful interpretations of statistical information within both scientific learning contexts and real-life situations.

The improvement in the indicator related to understanding elements of research design (70.37%) indicates that students not only acquired technical procedural knowledge but also developed a deeper comprehension of the relationships among variables, methodological structures, and research stages. This outcome is consistent with international literature highlighting the importance of scientific inquiry in fostering scientific literacy. Empirical studies have demonstrated

that inquiry-based engagement promotes active student involvement in evaluating evidence and addressing authentic problems (Ding, 2022).

In contrast, the indicator assessing the evaluation of the use and misuse of scientific information exhibited a relatively lower gain (32.08%). This suggests that evaluative competencies related to identifying bias and interpretative inaccuracies require further pedagogical reinforcement. Such findings are not unique to the Indonesian context; international research similarly identifies critical and evaluative thinking as among the most challenging dimensions of scientific literacy to cultivate and assess reliably within applied educational settings (Ploj Virtič, 2022).

The observed pattern of differential improvement reinforces the view that scientific literacy is not a singular, uniform competence but rather a multidimensional construct that responds variably to instructional interventions. These findings support international scholarship asserting that project-based pedagogies emphasizing exploration, data analysis, and scientific argumentation contribute substantively to the development of students' scientific literacy, particularly in terms of application, interpretation, and evidence-based decision-making (Eppler et al., 2021; Feinstein and Waddington, 2020).

The variation in achievement across indicators indicates that, although the learning model effectively enhanced quantitative and analytical competencies, dimensions requiring higher-order critical and reflective skills—such as the evaluation of scientific arguments—necessitate more deliberate attention in subsequent instructional design. This perspective aligns with recommendations from international educational research, which emphasize that authentic science learning should extend beyond hands-on activities to include structured opportunities for critical reasoning, argumentative discourse, and the rigorous evaluation of complex evidence (Ariely and Yarden, 2025).

The findings are particularly relevant to the Indonesian higher education context, where previous studies have consistently reported moderate levels of scientific literacy among university students (Suwono et al. 2023, 2017). The strong gains observed in data interpretation and statistical reasoning suggest that authentic project-based scientific experiences may help address persistent weaknesses identified among Indonesian biology and health science students.

The substantial gain in statistical literacy observed in the present study is consistent with the findings of (Webster et al. 2022), who reported that project-based investigations enhanced students' abilities to analyze empirical data. However, unlike previous studies that reported only overall literacy gains, the present study demonstrates that statistical reasoning emerged as the most responsive dimension of scientific literacy.

LIMITATIONS

This study has several limitations that should be considered when interpreting the findings. The research employed a one-group pretest–posttest design without a control group; therefore, the observed improvements in scientific literacy cannot be conclusively compared with outcomes derived from alternative instructional models. External factors beyond the instructional intervention may also have influenced students' performance during the study period. In addition, the sample was limited to a single study program within one higher education institution, thereby restricting the generalizability of the findings to broader educational contexts. The duration of the instructional implementation, which spanned half a semester, did not permit examination of the long-term sustainability of the observed improvements in scientific literacy. Future research employing experimental designs that incorporate control groups, more diverse and representative samples, and longitudinal measurements is necessary to provide a more comprehensive understanding of the effectiveness of the Citizen Science Project learning model in fostering students' scientific literacy.

CONCLUSIONS

This study demonstrates that the implementation of the Citizen Science Project (CSP) learning model contributes positively to the development of students' scientific literacy in higher education. The findings revealed a substantial increase in overall scientific literacy scores, accompanied by differential patterns of improvement across indicators. The most pronounced gains were observed in understanding and interpreting basic statistics, graph interpretation, and evidence-based inference, whereas the evaluation of the use and misuse of scientific information showed comparatively lower improvement. These results indicate that scientific literacy develops unevenly across its dimensions and that instructional interventions may influence particular competencies more strongly than others.

From a theoretical perspective, this study provides empirical support for the multidimensional nature of scientific literacy by demonstrating that indicator-level analysis can reveal patterns of development that are not visible through aggregate scores alone. The findings extend previous research on project-based and citizen science learning by identifying specific scientific literacy dimensions that are most responsive to authentic scientific investigations. Consequently, the study contributes to a more nuanced understanding of how scientific literacy develops within higher education contexts.

Practically, the results suggest that higher education instructors should integrate authentic data collection, analysis, and evidence-based reasoning activities into science learning environments. At the same time, greater instructional attention should be directed toward fostering students' critical evaluation of scientific information, argumentation skills, and the identification of misinformation, as these competencies exhibited the lowest gains.

Future research should employ experimental or quasi-experimental designs involving comparison groups to provide stronger evidence regarding the effectiveness of the Citizen Science Project model. In addition, longitudinal studies are needed to examine the sustainability of scientific literacy gains over time and to explore how different scientific literacy dimensions evolve across diverse academic disciplines and educational contexts.

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