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Enhancing Environmental Literacy through Project-Based Digital Herbarium and Citizen Science in Nonformal Education

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ABSTRACT

This community service program aimed to enhance students' environmental literacy, observational skills, and digital literacy through the implementation of project-based learning by developing a participatory digital herbarium at Sanggar Bimbingan Wira Damai, Batu Caves, Selangor, Malaysia. The program was initiated in response to challenges in biology learning, which tended to be theoretical, lacked documentation of local biodiversity, and showed limited student engagement in environmental exploration. The implementation involved 20 students and applied a combination of socialization, training, field exploration, and mentoring activities. Data were collected using pretest and posttest assessments, observation sheets, and documentation. The results indicated a significant improvement in learning outcomes, reflected by an increase in the mean score from 57.95 to 82.25, with an N-Gain of 0.58 (moderate category). In addition, the program successfully produced a web-based digital herbarium and demonstrated improvements in students' observational skills, technological competence, and conservation awareness. Overall, the integration of project-based learning with biodiversity-based digital technology proved to be an effective and adaptive approach for improving biology learning quality in nonformal education settings with limited resources, while also providing sustainable learning tools for the partner institution.

INTRODUCTION

The rapid advancement of digital technology has significantly reconfigured the paradigm of biology education, particularly through the integration of digital herbariums and biodiversity databases as data-driven learning resources. The digitization of biodiversity collections has been shown to expand access to ecological information, enhance biological literacy, and improve students' analytical skills in understanding biodiversity dynamics (Cota-Sánchez, 2020; La Salle et al., 2016). Furthermore, digital herbariums enable more efficient and accurate species identification processes while supporting data-driven conservation based on open-access biodiversity data (Setiawan et al., 2020). At a global level, biodiversity digitization also plays a crucial role in supporting open-data-based ecological research and enabling the integration of big biodiversity data into modern science education (Heberling, 2021; Paton et al., 2025). Digitized biological collections facilitate interdisciplinary integration across education, conservation, and large-scale data analysis, which are essential competencies in 21st-century learning.

Despite these advancements, the implementation of digital herbarium-based learning remains largely confined to formal educational settings with adequate infrastructure. In practice, digital herbariums are often used merely as visualization tools or identification aids, rather than as comprehensive data-driven learning ecosystems that actively engage students in scientific inquiry. This limitation reveals a gap between the technological potential of biodiversity digitization and its application in nonformal educational contexts, where resources are often constrained (Sari et al., 2024). In parallel, the emergence of citizen science has opened new opportunities for public participation in scientific data production (Herodotou et al., 2022), particularly in biodiversity research. Citizen science significantly contributes to large-scale ecological data collection while simultaneously enhancing public scientific literacy (Fraisl et al., 2022). Furthermore, public engagement in biodiversity observation through digital platforms not only generates valid scientific data but also strengthens environmental awareness and conservation behavior (Chandler et al., 2017).

However, within educational contexts, students are still predominantly positioned as consumers of data rather than producers of scientific knowledge. This reflects a conceptual gap between data-driven learning and participatory scientific practices (Gusti et al., 2024). Moreover, the application of citizen science in micro-scale educational settings, particularly in nonformal education, remains sporadic and insufficiently integrated into systematic pedagogical designs (Ramadhani et al., 2024). These challenges are evident in the learning practices at Sanggar Bimbingan Wira Damai, Batu Caves, Selangor, Malaysia, the partner institution in this community service program. Preliminary observations revealed several operational problems in biodiversity learning. First, students' involvement in exploratory environmental activities remains low, as biology learning is still predominantly theoretical and classroom-oriented. Second, limitations in laboratory facilities and learning media restrict students' opportunities to conduct direct observation and scientific investigation. Third, the institution does not yet possess systematic documentation of local flora that can be utilized as contextual learning resources. As a result, students have limited experience in conducting biodiversity observation, recording ecological data, and participating in environmental conservation practices. These conditions consequently contribute to low environmental literacy, weak scientific inquiry skills, and minimal student participation in biodiversity conservation activities.

The findings are further supported by a needs assessment, which revealed that students' pretest scores ranged from 50 to 65, with an average of 57.95, indicating a low baseline understanding of biodiversity and conservation concepts. This suggests a misalignment between instructional approaches and learners' needs, highlighting the urgency for an intervention that emphasizes experiential learning while integrating scientific skills and digital competencies. In this context, strengthening literacy competencies becomes essential. Data literacy is defined as the ability to access, interpret, critically evaluate, and effectively use data for decision-making (OECD, 2018). This includes competencies in data interpretation, validation, and communication of evidence-based findings. Meanwhile, ecological literacy refers to an individual's capacity to understand ecological principles, recognize the interdependence between humans and the environment, and demonstrate responsible behavior toward sustainability (UNESCO, 2017). Importantly, ecological literacy extends beyond conceptual understanding to include attitudes and actions that support environmental conservation.

The integration of data literacy and ecological literacy is therefore critical in biodiversity education, particularly in digital learning environments. However, existing educational practices tend to develop these literacies separately, resulting in fragmented learning experiences that fail to connect data analysis with ecological awareness and real-world environmental action. In nonformal educational settings, especially those with limited resources, learning practices that integrate digital herbarium utilization, project-based learning (PjBL), and citizen science are still rarely implemented in a structured and contextual manner. This condition indicates a practical and pedagogical gap in biodiversity learning, where students have not been optimally facilitated to develop scientific participation, ecological awareness, and digital competencies simultaneously. Accordingly, the novelty of this community service program lies in the development of an integrative learning model that: (1) combines digital herbariums and biodiversity platforms as data-driven learning resources; (2) repositions students as active producers of scientific data through citizen science; and (3) integrates data literacy and ecological literacy within a contextual and resource-adaptive nonformal education framework. This approach extends previous studies, which have largely been implemented separately, into a more comprehensive and contextually relevant pedagogical model for nonformal biodiversity education.

To address the identified challenges, this community service program implements a three-phase instructional intervention: (1) a preparation phase involving needs assessment and digital literacy training; (2) an implementation phase consisting of environmental exploration, specimen documentation, and participatory digital herbarium development; and (3) a reflection phase involving data analysis, presentation, and reinforcement of conservation awareness. This model is designed to systematically integrate cognitive processes, scientific skills, and digital competencies. Therefore, the objectives of this study are: (1) to enhance students' environmental literacy through project-based learning; (2) to develop observational skills and digital literacy through the use of digital herbariums; and (3) to foster conservation awareness through the integration of environmental exploration and digital technology within a citizen science framework.

IMPLEMENTATION METHOD

This community service program employed an educational intervention design using a combination of project-based learning (PjBL), training, and mentoring approaches grounded in citizen science. The selection of this approach was based on its alignment with the partner's identified problems, namely low student engagement in environment-based learning, as well as limitations in data literacy and observational skills. PjBL was chosen due to its capacity to integrate conceptual knowledge with contextual experience through the completion of authentic projects, while training and mentoring were incorporated to ensure the transfer of technical skills and the sustainability of program implementation.

The target participants of this program were students at Sanggar Bimbingan Wira Damai, Batu Caves, Selangor, Malaysia, a nonformal educational institution for Indonesian students living abroad. A total of 20 students were involved as participants using a total sampling technique. The participants were characterized as secondary school-aged students with heterogeneous backgrounds in biodiversity knowledge and scientific skills. The selection of this partner was based on actual needs, including low environmental literacy, limited laboratory facilities, and the underutilization of the surrounding environment as a learning resource. The program was conducted at the Sanggar Bimbingan Wira Damai and the surrounding Batu Caves area in Selangor, Malaysia.

The program was conducted at Sanggar Bimbingan Wira Damai and the surrounding Batu Caves area in Selangor, Malaysia. The community service activities were implemented from September to December 2025, consisting of preparation, implementation, evaluation, and dissemination phases. The preparation stage, including initial coordination, needs assessment, and Focus Group Discussion (FGD), was conducted from 10–25 September 2025. Administrative coordination and institutional permission processes were carried out in October 2025. The main implementation activities, including biodiversity socialization, environmental exploration, flora identification, and digital herbarium mentoring, were conducted on 20–22 November 2025. Subsequently, data processing, reflection, reporting, and dissemination activities were completed from November to December 2025.

The materials, tools, and media used in this program included: (1) biodiversity learning modules as instructional guides, (2) test instruments (pretest and posttest), (3) observation sheets, (4) documentation tools (cameras and field notes), (5) simple sampling tools for flora collection, and (6) a web-based digital herbarium platform for biodiversity data management and storage. The digital platform utilized was adapted to the technological accessibility of the partner institution. The implementation procedures were carried out systematically in several stages. The first stage involved problem identification and program planning, including coordination with the partner, conducting a needs assessment through observations and interviews, and developing learning materials and evaluation instruments. At this stage, instrument validation was conducted by experts to ensure alignment between theoretical constructs and measured indicators.

The second stage was the implementation phase, which began with a socialization session on biodiversity and conservation concepts, followed by technical training on digital herbarium usage, sampling techniques, and specimen documentation. Subsequently, students engaged in environmental exploration to identify local flora, collect data, and develop a digital herbarium as a learning product. Intensive mentoring was provided throughout this phase to ensure active participation and the effectiveness of the project-based learning process. The third stage involved evaluation and follow-up, which included measuring learning outcomes through a posttest, analyzing the digital herbarium products, and conducting reflective discussions between participants and facilitators. This stage also aimed to reinforce conservation awareness and identify opportunities for program sustainability.

Data collection techniques employed in this study included a combination of: (1) written tests (pretest and posttest) to measure cognitive improvement, (2) direct observation to capture student engagement and scientific process skills, (3) limited semi-structured interviews to obtain participant feedback regarding learning experiences, challenges encountered during environmental exploration, and perceptions toward the use of digital herbariums and citizen science activities, and (4) documentation in the form of photographs, videos, and field notes as supporting data. The evaluation instruments consisted of validated pretest and posttest items (content validity assessed by biology education experts) and structured observation sheets to assess student participation and activity levels. The reliability of the test instruments was measured using Cronbach's Alpha coefficient, with a minimum acceptable value of 0.70. To enhance objectivity, observations were conducted by more than one observer using an inter-rater agreement approach.

Data analysis was performed using both quantitative and qualitative descriptive approaches. Quantitative data were analyzed by comparing pretest and posttest scores and calculating the N-Gain to determine the proportional effectiveness of the intervention. Meanwhile, qualitative data obtained from observations, interviews, and documentation were analyzed descriptively to provide a comprehensive understanding of the learning process and the impact of the intervention. Data analysis was performed using both quantitative and qualitative descriptive approaches. Quantitative data were analyzed by comparing pretest and posttest scores and calculating the N-Gain to determine the proportional effectiveness of the intervention. Meanwhile, qualitative data obtained from observations, interviews, and documentation were analyzed descriptively to provide a comprehensive understanding of the learning process and the impact of the intervention. Overall, the integration of project-based learning (PjBL), training, and mentoring approaches was considered appropriate for addressing the partner institution's needs, particularly in improving students' scientific participation, observational skills, digital literacy, and environmental awareness. This integrative approach also supported the sustainability and contextual relevance of biodiversity learning within nonformal educational settings. Therefore, the approach employed was considered relevant and adaptive in addressing the identified problems and supporting the sustainability of community-based educational programs.

RESULTS AND DISCUSSION

This community service program involved 20 students at Sanggar Bimbingan Wira Damai. The improvement in environmental literacy was measured by comparing pretest and posttest scores, which were further analyzed using the N-Gain index. The descriptive statistical results are presented in Table 1.

Table 1. Descriptive Statistics of Pretest, Posttest, and N-Gain Scores

Variable	N	Mean	SD	Minimum	Maximum	Category
Pretest	20	57.95	4.15	50	65	Low
Posttest	20	82.25	3.42	77	88	High
N-Gain	20	0.58	0.05	0.52	0.66	Moderate

The descriptive statistical results presented in Table 1 indicate an increase in participants' environmental literacy following the implementation of the program. The mean pretest score was

57.95, which increased to 82.25 in the posttest results. In addition, the average N-Gain score reached 0.58, which falls within the moderate category. The minimum and maximum N-Gain scores ranged from 0.52 to 0.66, indicating that learning improvement occurred relatively consistently among participants. Figure 1 further illustrates the overall tendency of learning improvement through the comparison of mean, minimum, and maximum N-Gain scores. These findings demonstrate that the intervention contributed positively to the enhancement of students' understanding of biodiversity and environmental conservation concepts.

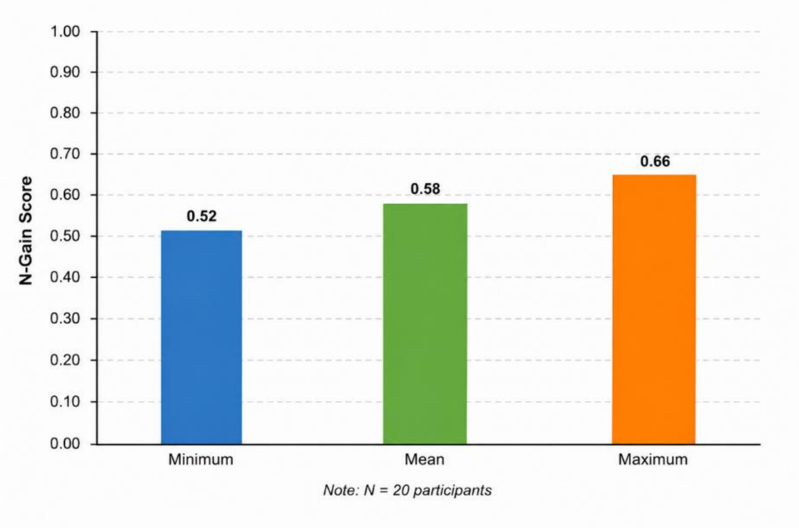

Figure 1. Summary of Participants' N-Gain Scores

Figure 1 shows that the mean N-Gain score was positioned within the moderate category, with relatively small differences between the minimum and maximum values. This finding indicates that the learning improvement achieved through the program tended to occur consistently across participants. The relatively stable distribution of N-Gain scores suggests that the integration of project-based learning, environmental exploration, and digital herbarium activities provided balanced learning opportunities for students with different initial competency levels. These results further support the effectiveness of participatory and contextual learning approaches in strengthening environmental literacy within nonformal educational settings.

The observation results indicate that participants were actively engaged throughout all stages of the program, from the initial socialization sessions and training to field exploration activities. The main activities included group discussions, plant identification, and biodiversity data processing. All participants completed the entire program and contributed to the development of a web-based digital herbarium as the final output of the activity. The documentation collected during the implementation of the community service program includes activity photographs (Figures 2), video recordings, participant attendance lists, training modules, and presentation materials. The photographs illustrate various stages of the program, ranging from initial socialization and technical training to field exploration and the development of a digital herbarium. The video documentation captures participants' activities throughout the program, including plant identification processes and the use of digital tools. The attendance records indicate that all participants were fully engaged and attended the program in its entirety. The training modules and presentation materials functioned as instructional guides during the activities and as learning resources for participants. In addition, a complete set of research graphs is provided in the appendix, covering pretest and posttest data, N-Gain analysis, and questionnaire results, serving as part of the program evaluation documentation. As part of the community service implementation, various activities were conducted across several partner locations. The following documentation illustrates a series of activities, including visits to educational institutions, the presentation of plaques as a symbol of collaboration, and direct interactions with students throughout the program.

Figure 2. Community Service Activities.

The primary output of the program was the development of a web-based digital herbarium containing local flora data collected through participants' field explorations. In addition, there was a noticeable improvement in observational skills and the use of digital technology, as evidenced by participants' ability to identify plant species, document specimens, and digitalize biodiversity data. To further illustrate the implementation of the digital herbarium platform, the user interface of the website is presented in Figure 3.

Figure 3. User Interface of a Learning-Based Digital Herbarium Website for Biodiversity Exploration.

To assess participants' responses to the implementation of the program, data were collected through a questionnaire covering several key aspects, namely satisfaction, interest, understanding, skills, awareness, and sharing. The results of the questionnaire analysis are presented in the following graph.

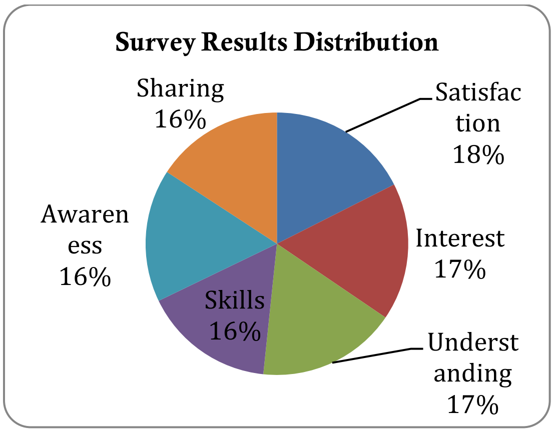

Figure 4. Distribution of Participants' Questionnaire Responses to the Program.

The questionnaire results indicate a highly positive response to the program, with satisfaction at 90%, interest at 87%, understanding at 88%, skills at 83%, awareness at 84%, and sharing at 81%. These findings suggest that the program was not only effective in enhancing cognitive outcomes but also provided an engaging and meaningful learning experience for the participants. Findings from the limited semi-structured interviews also supported the questionnaire results. Several participants reported that the environmental exploration activities provided a new learning experience because they were directly involved in identifying and documenting local plant species. Participants also expressed increased awareness regarding the importance of biodiversity conservation and stated that the use of digital herbarium technology made biology learning more interactive and engaging. However, some participants initially experienced difficulties in using digital documentation tools and organizing biodiversity data systematically, particularly those with limited prior experience in digital learning activities. These responses indicate that participatory and technology-assisted learning approaches can enhance both student motivation and scientific engagement within nonformal educational settings. Overall, the quantitative and qualitative findings consistently demonstrate positive learning outcomes following the implementation of the program.

The results of this program indicate that the integration of project-based learning (PjBL), digital herbarium, and a citizen science approach significantly contributed to the improvement of students' environmental literacy. The increase in the mean score from 57.95 to 82.25, with an N-Gain value of 0.58, suggests that the intervention was effective in enhancing both conceptual understanding and participants' applied skills. These findings are consistent with previous studies demonstrating that PjBL can improve environmental literacy and higher-order thinking skills through experiential learning (Pertiwi et al., 2024; Sari et al., 2024). Moreover, international research has confirmed that project-based learning has a significant effect on improving student engagement and learning retention compared to conventional approaches (Kokotsaki et al., 2016). From a theoretical perspective, these findings reinforce the constructivist framework, which emphasizes that knowledge is constructed through direct experience, social interaction, and reflection on real-world phenomena (Vygotsky, 1978). Environmental exploration activities and the development of a digital herbarium provided authentic learning experiences that enabled students to connect biodiversity concepts with ecological realities. This is aligned with the place-based learning approach, which has been proven effective in enhancing ecological awareness and environmental attachment (Ardoin et al., 2020).

Furthermore, the use of a digital herbarium as a learning medium serves as a bridge between theoretical concepts and empirical experiences. The digital herbarium enabled students to document plant specimens systematically, organize biodiversity information, and access ecological data in a more contextual manner. Studies by Cota-Sánchez (2020), Heberling et al. (2021), and Paton et al. (2024) indicate that herbarium digitization enables broader integration of biodiversity data into educational activities. In addition, biodiversity databases and digital platforms have been shown to improve students' data literacy, analytical skills, and understanding of biological concepts (Eckert et al., 2024; Nelson & Ellis, 2018). In this program, the digital herbarium functioned not only as a repository of local flora data but also as an interactive learning resource that facilitated environmental exploration and scientific inquiry.

Another important contribution of this program lies in the integration of citizen science practices into biodiversity learning. Through observation, identification, documentation, and data digitalization activities, students were positioned as active contributors to biodiversity data production rather than passive recipients of information. This participatory process aligns with the citizen science approach, which emphasizes public involvement in scientific knowledge production (Bonney et al., 2016; Chandler et al., 2017; Fraisl et al., 2022). Previous studies also suggest that integrating citizen science into educational settings can strengthen environmental awareness, scientific participation, and conservation behavior (Gusti et al., 2024; Ramadhani et al., 2024). Therefore, this program contributed not only to cognitive learning outcomes but also to students' sense of environmental responsibility and scientific engagement.

From a literacy perspective, the integration of ecological literacy and digital literacy represents a key strength of this program. Students not only developed an understanding of biodiversity concepts but also gained the ability to manage data systematically using digital technologies. This is consistent with the 21st-century learning framework, which emphasizes the integration of data literacy, digital literacy, and environmental literacy in science education (OECD, 2018; UNESCO, 2017; Voogt et al., 2013). Recent studies further demonstrate that biodiversity data-driven learning enhances students' ability to interpret data and make evidence-based decisions (Firmansyah & Ramadhan, 2025; Oliveira et al., 2025). Another important finding is the successful implementation of the program under limited resource conditions. The results indicate that technology-based educational innovation does not necessarily depend on advanced infrastructure but can be achieved through the optimization of locally available resources. This aligns with the concept of low-resource innovation, which is particularly relevant in developing countries (Kapur & Bielaczyc, 2012). In the context of community service, training and mentoring approaches have also been shown to effectively enhance participants' capacity (Djuhartono et al., 2025; Hairunisa et al., 2025).

In terms of impact, the program improved not only cognitive outcomes but also observational skills, technological literacy, and conservation awareness. Questionnaire results indicating high levels of satisfaction suggest a positive impact on affective and behavioral dimensions. These findings are consistent with studies showing that experiential and participatory learning approaches enhance student motivation and engagement (Deci & Ryan, 2000). Additionally, direct involvement in local biodiversity exploration strengthens emotional connections to the environment (Soga et al., 2025), which is a critical factor in shaping pro-environmental behavior (Clayton et al., 2013). However, several limitations should be acknowledged. First, the relatively small number of participants and the short duration of the intervention limit the generalizability of the findings and the assessment of long-term impacts. Second, variations in participants' initial digital literacy levels created differences in the speed of adaptation during digital herbarium activities. Some participants experienced difficulties in operating mobile-based documentation tools, organizing biodiversity data, and uploading specimen information to the digital platform. In addition, limited internet connectivity during several field exploration sessions affected the efficiency of real-time data input and online access to biodiversity references. To mitigate these challenges, facilitators implemented intensive mentoring, peer-assisted learning strategies, simplified technical guidelines, and offline data recording prior to digital uploading sessions. These adaptive strategies helped maintain participant engagement and ensured the continuity of the learning process despite resource limitations. These findings are consistent with previous studies indicating that the successful implementation of PjBL and technology-based learning requires sufficient time, adaptive facilitation, and differentiated instructional support (Bin Abdul Wahab & Binti Husnin, 2025; Fitri et al., 2024; Haryanti et al., 2025; Ratih et al., 2024; Sukanti et al., 2025).

For future development, longer-term program implementation is recommended, along with integration into global biodiversity platforms such as iNaturalist to enhance the scientific value of the collected data. Additionally, replicating the model in different nonformal education contexts would strengthen its external validity. International studies suggest that integrating global biodiversity data into learning can improve educational quality and contribute to biodiversity research (Fraisl et al., 2022; Heberling, 2021). Overall, this program successfully achieved its objectives by improving students' environmental literacy, observational skills, and digital literacy through a project-based learning approach. The integration of environmental exploration and digital technology emerged as a key success factor, contributing to the development of an innovative, adaptive, and contextual biology learning model (Haleem et al., 2022; Husamah et al., 2025), particularly in nonformal education settings with limited resources.

CONCLUSION

This community service program demonstrates that the integration of project-based learning, digital herbarium activities, and a citizen science approach effectively improved students' environmental literacy, observational skills, and digital literacy at Sanggar Bimbingan Wira Damai. The program also increased students' active participation in biodiversity exploration and strengthened their awareness of environmental conservation through contextual and technology-assisted learning experiences. Practically, the web-based digital herbarium developed during the program serves as a sustainable learning resource that can support biodiversity education in nonformal learning environments with limited resources. For future development, strengthening digital literacy and expanding the implementation of the program into broader biodiversity platforms are recommended to enhance the sustainability and educational impact of the model.

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