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Black Soldier Fly Cultivation as Experiential Learning: A Mixed-Methods Study of Ecoliteracy and Circular Economy Education in an Indonesian Community Learning Center

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Abstract

Background – Organic waste management remains a major environmental challenge in Indonesia, requiring not only technological solutions but also educational approaches that promote environmental awareness and sustainable behavior. Black Soldier Fly (BSF) cultivation offers a practical approach that integrates organic waste management with environmental education and circular economy principles.
Research Urgency – Despite growing interest in BSF cultivation for waste management, limited studies have explored its role as a learning medium for eco-literacy development and circular economy education, particularly in nonformal education settings.
Research Objectives – This study aims to explore, through an exploratory mixed-methods case study, how BSF cultivation functioned as a learning strategy and experiential learning medium for eco-literacy development and circular economy education through the Maggotpreneur Program at PKBM Bhina Swakarya.
Research Method – This study used an embedded mixed-methods case study design with a one-group pretest–posttest component, conducted over three weeks. Of 53 Package B and Package C learners initially assessed for experience and interest, 34 joined the training program, and the 14 who joined the BSF cultivation learning group (ages 14–45) and completed both pretest and posttest assessments formed the main analytic sample. Quantitative data (a 15-item knowledge test) were analyzed using paired-samples statistics and N-Gain scores; qualitative data from field observations and participant reflections were analyzed through iterative coding, categorization, and interpretation. Given the one-group design without a comparison group and the small sample, this study is exploratory in nature.
Research Findings – Knowledge scores increased significantly from pretest to posttest, $t(13) = 4.41$, $p < .001$, with a mean N-Gain of 0.59 (moderate) and a large effect size (Cohen's $d = 1.18$), indicating a learning improvement in participants' understanding of organic waste management and circular economy concepts. Qualitative observations suggested increased environmental awareness and a shift in some participants' perceptions of organic waste, from viewing it as a disposal problem toward recognizing it as a resource with environmental and economic value.
Research Conclusion – As an exploratory case study, this research provides preliminary evidence that BSF cultivation can serve as an experiential and contextual learning medium for promoting eco-literacy and circular economy education in nonformal education settings; confirmatory studies with comparison groups are needed to establish effectiveness.
Research Novelty/Contribution – This study contributes by positioning BSF cultivation not only as an organic waste management practice but also as an experiential learning medium for eco-literacy development and circular economy education within a nonformal education context, specifically through the Maggotpreneur Program at a community learning center (PKBM) in Indonesia.
Keywords: Black Soldier Fly cultivation; eco-literacy; circular economy education

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INTRODUCTION

Organic waste management remains one of the most pressing environmental challenges in Indonesia. Rapid population growth, urbanization, and changing consumption patterns have contributed to a significant increase in municipal waste generation (Kaza et al., 2018). According to national reports, organic waste constitutes the largest proportion of household waste, and improper management often results in environmental pollution, greenhouse gas emissions, unpleasant odors, and public health risks (SIPSN KLHK, 2023). Recent waste crises in several regions of West Java have further highlighted the urgency of developing sustainable and community-based approaches to waste management. Addressing this issue requires not only technological solutions but also educational interventions that foster environmental awareness and responsible behavior toward waste management (UNESCO, 2020).

One approach that has gained increasing attention is the circular economy. The circular economy challenges the conventional linear model of "take–make–dispose" by promoting resource efficiency, waste reduction, reuse, and regeneration (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Kirchherr et al., 2023). Within this framework, waste is viewed not as an endpoint but as a resource that can be transformed into products with environmental and economic value (Korhonen et al., 2018; Borrello et al., 2017). Consequently, circular economy principles have become increasingly relevant in environmental education because they encourage individuals to understand the relationship between consumption, waste generation, and resource recovery (Ellen MacArthur Foundation, 2022). Recent scholarship also cautions that circularity should not be treated as automatically sustainable because social, institutional, and material trade-offs remain important (Corvellec et al., 2022).

Among various circular economy practices, Black Soldier Fly (BSF) cultivation has emerged as a promising strategy for managing organic waste. BSF larvae can efficiently convert organic waste into protein-rich biomass while substantially reducing waste volume (Tomberlin et al., 2009; Surendra et al., 2020; Lalander et al., 2019; Kim et al., 2021). The harvested larvae can be utilized as animal feed, while the residual substrate may be processed into organic fertilizer (Juliana et al., 2022; van Huis et al., 2013; Gold et al., 2020; Kim et al., 2021). Previous studies have primarily focused on the technical and economic aspects of BSF cultivation (Mertenat et al., 2019; Surendra et al., 2020; Kim et al., 2021). However, its potential as an educational medium for promoting environmental learning remains underexplored. Recent studies further support the use of BSF systems for municipal organic-waste recovery, productive reuse of frass, and decentralized circular-economy applications (Salam et al., 2021; Lopes et al., 2022; Ramzy et al., 2025). Empirical work confirms that BSF performance depends on feedstock, moisture, and environmental conditions and that household and community applications can reduce organic-waste burdens (Bekker et al., 2021; Mahmood et al., 2021; Salam et al., 2022; Singh et al., 2021). Reviews also identify BSF as a technically promising, though context-dependent, pathway for waste treatment and resource recovery (Purkayastha & Sarkar, 2022b; Rehman et al., 2023; Siddiqui et al., 2022). System-level studies further highlight manure recycling, mixed-waste treatment, life-cycle impacts, feed supply chains, and circular-bioeconomy value creation (Bukchin-Peles et al., 2025; Ferronato et al., 2024; Liu et al., 2022; Purkayastha & Sarkar, 2022a; Raman et al., 2022).

The educational value of BSF cultivation is closely associated with the concept of eco-literacy. Eco-literacy refers to an individual's ability to understand ecological systems and apply such understanding in making environmentally responsible decisions (Orr, 1992). Similarly, Capra (1999) emphasizes that eco-literacy involves recognizing the interconnectedness between human activities and natural systems. Environmental education scholars argue that eco-literacy is most effectively developed through authentic experiences that allow learners to interact directly with environmental issues and solutions (McBride et al., 2013; UNESCO, 2020). Eco-literacy is broader than related constructs with which it is sometimes conflated: environmental literacy typically emphasizes cognitive knowledge of ecological facts and issues, whereas eco-literacy additionally encompasses attitudes, awareness, and the practical skills and actions needed to apply that

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understanding (Orr, 1992; Capra, 1999). Circular economy competency, in turn, refers more specifically to the knowledge and skills needed to apply circular principles, such as resource recovery and waste valorization, in practice (Kirchherr et al., 2017). This study draws on eco-literacy as the broader construct while operationalizing it, for measurement purposes, primarily through its knowledge component. Therefore, learning activities that engage participants in practical environmental problem-solving may provide meaningful opportunities for eco-literacy development. This educational role is consistent with recent evidence identifying education as a central mechanism for translating circular-economy principles into awareness and action (Tiippana-Usvasalo et al., 2023). Recent studies further emphasize that circular-economy education requires sustainability competencies, cross-disciplinary learning, and links between education and professional practice (Del Vecchio et al., 2021; Janssens et al., 2021; Serrano-Bedia & Pérez-Pérez, 2022).

This perspective is consistent with Experiential Learning Theory, which posits that knowledge is constructed through a continuous cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984). In environmental education, experiential learning enables learners to connect theoretical concepts with real-world environmental challenges (Dewey, 1938). Previous studies have demonstrated that hands-on environmental activities can enhance environmental awareness, engagement, and understanding among learners (Monroe et al., 2019; Renfors, 2024).

The relevance of such learning experiences is particularly significant in nonformal education settings. Nonformal education institutions play an important role in providing flexible and context-based learning opportunities that address community needs and local challenges (Rogers, 2005; Kamil, 2011; Knowles et al., 2015; UNESCO Institute for Lifelong Learning, 2022; Hayat et al., 2024; Prasetyo et al., 2024). In Indonesia, Package B and Package C equivalency programs serve diverse groups of learners, including school-age youth who often require practical and meaningful learning experiences beyond conventional classroom instruction. Many young learners in such programs have had limited prior hands-on exposure to agricultural or environmental practices that require patience, responsibility, and direct engagement with living organisms. Consequently, environmental learning programs must adopt innovative approaches that can attract learners' interest while simultaneously promoting meaningful learning outcomes. Recent JoNE studies further show that nonformal education supports human-resource development, lifelong learning for rural sustainability, and collaborative community-based learning media (Darmawan et al., 2025; Melania et al., 2024; Prasetyo & Kusumawardani, 2025).

To address these challenges, PKBM Bhina Swakarya developed the Maggotpreneur Program, an educational initiative integrating environmental education, entrepreneurship, and circular economy principles through BSF cultivation activities. The program adopted the tagline “Turning Waste into Blessings” (Mengubah Sampah Menjadi Berkah) to emphasize the transformation of organic waste from an environmental burden into a valuable resource. Prior to implementation, an initial assessment involving 53 learners was conducted to identify participants’ experiences and interests related to BSF cultivation and entrepreneurship. Following introductory training sessions, 34 learners participated in the program, of whom 14 joined the BSF maggot cultivation learning group. This study specifically focuses on these participants, who were directly involved in BSF cultivation activities. The program's initial assessment also reflects the importance of identifying community learning priorities before designing activities at a Community Learning Center (Purnomo et al., 2024).

Previous studies within community education and environmental entrepreneurship programs have highlighted the potential of experiential environmental learning in fostering learner engagement and practical skills development (Monroe et al., 2019; Ratnasari et al., 2021). Nevertheless, while recent studies have examined environmental literacy and eco-friendly curriculum strategies in Indonesian educational settings more broadly (Anawati & Utari, 2023; Triyandana et al., 2024), limited research has specifically examined how direct involvement in BSF cultivation contributes to eco-literacy development and understanding of circular economy concepts among learners in nonformal, equivalency-education (Package B/C) settings such

as PKBMs. This gap is particularly relevant given the growing need for educational approaches that integrate environmental sustainability, entrepreneurship, and community empowerment. Related JoNE studies also show that learning-community and coaching-based approaches can connect nonformal education with empowerment and entrepreneurship objectives (Yusmanto et al., 2024; Widodo et al., 2024). They also emphasize pedagogical strategies and systematic program evaluation as important elements of skills-oriented training (Adeoye et al., 2024; Akhadi & Shofwan, 2024).

Therefore, this study adopts an exploratory mixed-methods case study design to examine how Black Soldier Fly cultivation contributes to eco-literacy development and circular economy education among learners in a nonformal education setting. Specifically, the study investigates changes in learners' understanding of organic waste management and circular economy concepts, as well as shifts in their perceptions of organic waste following participation in BSF cultivation activities. Because the study relies on a one-group pretest–posttest design with a small sample and no comparison group, its findings are intended to generate exploratory, context-specific insight rather than to establish causal effectiveness. By addressing this gap, the study contributes to the growing literature on eco-literacy, experiential learning, and circular economy education in nonformal education contexts. Specifically, this study addresses the following research questions: (1) How does participation in BSF cultivation relate to changes in the knowledge component of learners' eco-literacy, as measured through pretest–posttest scores? (2) How do participants describe and demonstrate shifts in their awareness of, and perceptions toward, organic waste and circular economy principles over the course of the program?

METHODS

Research Design

This study employed an embedded mixed-methods case study design, with a one-group pretest–posttest component nested within the qualitative case study, to examine how Black Soldier Fly (BSF) cultivation contributed to eco-literacy development and circular economy education in a nonformal education setting. The mixed-methods approach was selected to provide a comprehensive understanding of both measurable learning outcomes and participants' learning experiences throughout the educational intervention (Creswell & Plano Clark, 2018). The case study design enabled an in-depth exploration of the Maggotpreneur Program as implemented within its real-life context at PKBM Bhina Swakarya (Yin, 2018). The quantitative component followed a one-group pretest–posttest design involving a small sample of 14 participants in the BSF maggot cultivation learning group, without a comparison or control group. This design does not permit causal claims of effectiveness; it is therefore treated as exploratory, and the quantitative results are interpreted alongside the qualitative findings to provide converging, context-specific evidence rather than confirmatory proof of impact.

Research Setting and Participants

The study was conducted at PKBM Bhina Swakarya, a community-based nonformal education institution in West Java, Indonesia. The institution provides equivalency education programs and community empowerment initiatives aimed at enhancing learners' life skills, entrepreneurship, and environmental awareness. The research was conducted in April 2026 at PKBM Bhina Swakarya, located in Batujajar, West Bandung Regency, West Java, Indonesia, through the Maggotpreneur Program, an educational initiative integrating environmental education, entrepreneurship, and circular economy principles through Black Soldier Fly cultivation activities. Prior to program implementation, an initial assessment was administered to 53 learners enrolled in Package B and Package C equivalency education programs. The assessment aimed to identify participants' prior experiences, interests, and perceptions regarding entrepreneurship and BSF cultivation.

Following an introductory session, 34 learners voluntarily participated in the program. Learners selected their learning activities according to their interests, and 14 of the 34 joined the BSF maggot cultivation learning

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group, as the intervention and assessment instruments were specifically designed to evaluate competencies in BSF cultivation, organic waste management, and eco-literacy. All fourteen participants who joined this learning group completed the intervention and both the pretest and posttest assessments and were therefore included in the analysis.

Participant Characteristics

Participants in the BSF maggot cultivation learning group ranged in age from 14 to 45 years and were drawn from Package B (junior-secondary equivalency) and Package C (senior-secondary equivalency) learners at PKBM Bhina Swakarya, together with a small number of community members from the surrounding area. This age range is consistent with the composition of Package B/C programs generally, which serve both school-age youth catching up on formal schooling and adult learners completing their equivalency education; it does not indicate that any individual participant fell outside this Package B/C or community-member profile. The 14 participants were those among the initially assessed learners who expressed interest in and voluntarily selected the BSF cultivation learning activity (see Initial Assessment, Table 1), rather than being randomly assigned. Of the 14 participants, 5 were female and 9 were male. The precise number of participants enrolled in Package B versus Package C was not systematically recorded in the program's documentation and is therefore not reported; this is acknowledged as a gap in the participant documentation for this exploratory study. Consistent with the broader learner population at this PKBM, most participants had no prior hands-on experience with BSF cultivation before the program (see Initial Assessment, Table 1).

Ethical Considerations

Prior to data collection, participants were informed about the objectives of the study, the voluntary nature of participation, confidentiality of the collected data, and their right to withdraw at any time without consequences. Permission to conduct the study was obtained from PKBM Bhina Swakarya. Because the BSF cultivation learning group included both school-age youth and adult learners, written informed consent was obtained from adult participants, and written parental/guardian consent together with participant assent was obtained for participants under 18 years old. No formal institutional ethical clearance number was issued for this exploratory, community-based study; participant confidentiality was maintained by referring to participants using anonymized codes (e.g., P1, P2) rather than names in data recording and reporting.

Program Design and Learning Activities

The Maggotpreneur Program was developed under the tagline "Turning Waste into Blessings" (Mengubah Sampah Menjadi Berkah), emphasizing the transformation of organic waste from an environmental burden into a valuable resource. The program was conducted over three weeks and adopted experiential learning principles (Kolb, 1984) combined with participatory learning approaches. Learning activities were designed to encourage active engagement, reflection, and direct interaction with environmental issues. Content on BSF biology, cultivation techniques, and quality standards was delivered by Nurul Ihsan, a BSF cultivation practitioner and community mobilizer active in the Bandung, Bandung City, and Cimahi area who manages several BSF cultivation units, who served as the program's resource person and cultivation trainer, using a structured operational cultivation guide; day-to-day facilitation and mentoring during sessions were provided by a team of graduate students from the Community Education (Pendidikan Masyarakat) master's program at Universitas Pendidikan Indonesia. Participants also conducted direct field observation of an existing, actively operating BSF cultivation unit at PKBM Bhina Swakarya. Each of the 14 participants prepared and managed an individual small-scale rearing unit made from a repurposed plastic gallon container, using organic waste from the PKBM's daily activities as feedstock. Precise weekly meeting frequency and hours per session were not separately logged in the program's documentation and are not reported here.

During the first week, participants received introductory sessions on environmental problems, organic waste management, circular economy concepts, and the life cycle of Black Soldier Fly. A pre-test was administered to assess participants' initial understanding. During the second week, participants engaged in practical activities involving waste sorting, feed preparation, BSF larval maintenance, feeding management, and observation of larval growth. Discussions were conducted to connect cultivation activities with environmental sustainability and circular economy principles. During the third week, participants carried out hands-on cultivation practices, harvesting activities, and reflective discussions regarding their learning experiences. A post-test was administered at the end of the program to evaluate learning outcomes. The learning process emphasized direct experience, observation, reflection, and application of knowledge, consistent with the stages of Experiential Learning Theory proposed by Kolb (1984) and the concept of learning through experience advocated by Dewey (1938).

Quantitative Data

Both quantitative and qualitative data were collected during the study. Quantitative data were obtained using a pre-test and post-test instrument consisting of 15 multiple-choice questions designed to assess participants' understanding of: organic waste management, black soldier fly cultivation, circular economy concepts, environmental sustainability. Each item was scored on a ten-point basis, resulting in a maximum possible score of 150. The 15 items were developed by the program facilitators and mapped directly onto the four learning indicators targeted by the intervention (organic waste management, BSF cultivation, circular economy concepts, and environmental sustainability). A formal content-validity procedure (e.g., expert judgment with an index such as Aiken's V or CVI) and pilot reliability testing (e.g., Cronbach's alpha or KR-20) were not conducted for this exploratory instrument; this is acknowledged as a limitation of the study, and the use of a psychometrically validated instrument is recommended for future confirmatory research.

Qualitative Data

Qualitative data were collected through facilitator observation during the second- and third-week hands-on cultivation sessions, informal group discussions held during and after these sessions, and participants' end-of-program reflections gathered via the same evaluation form used for the knowledge posttest. Observations and reflections were not collected using a structured protocol or formal interview guide, and were not sampled separately from the full group of 14 participants; this is acknowledged as a methodological limitation. Particular attention was given to indicators of eco-literacy development, including participants' awareness of environmental issues, understanding of waste as a resource, and perceptions regarding sustainable waste management practices.

Data Analysis

Quantitative Analysis

Quantitative data were analyzed using descriptive statistics and normalized gain (N-Gain) analysis to measure learning improvement resulting from the educational intervention (Hake, 1999).

The N-Gain score was calculated using the following formula:

$$G = \frac{\text{Posttest} - \text{Pretest}}{\text{Maximum Score} - \text{Pretest}}$$

The resulting N-Gain values were interpreted according to the following criteria:

- High: $g > 0.70$
- Moderate: $0.30 \leq g \leq 0.70$
- Low: $g < 0.30$

The average N-Gain score, calculated from the group mean pretest and posttest scores following Hake's (1999) formula, was 0.59, which falls within the moderate category; this corrects an earlier miscalculation in which the reported value (0.567) was not obtained from the group-mean formula. Because the design lacks a

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comparison group, this value is interpreted descriptively rather than as proof of causal effectiveness. A Shapiro-Wilk test indicated that the pretest-posttest difference scores did not significantly depart from normality ($W = 0.89$, $p = .094$), so a paired-samples t-test was used, with a Wilcoxon signed-rank test run as a robustness check. The increase from pretest ($M = 122.1$, $SD = 19.7$) to posttest ($M = 138.6$, $SD = 14.6$) was statistically significant, $t(13) = 4.41$, $p < .001$, 95% CI [8.5, 24.4] (Wilcoxon: $p = .003$), with a large effect size (Cohen's $d = 1.18$). Individual pretest, posttest, and N-Gain scores for all 14 participants, including the two whose scores decreased, are reported in Table 3, using anonymized participant codes (P1-P14). One participant (P7) began at the maximum possible score (150/150); an individual N-Gain could not be calculated for this participant because the denominator (150 minus pretest score) equals zero, so this case is reported separately as an already-at-ceiling result rather than included in the N-Gain average.

Table 1. Individual Pretest, Posttest, and N-Gain Scores (N = 14)

Participant Code	Pretest	Posttest	N-Gain	Category
P1	130	150	1.00	High
P2	120	130	0.33	Moderate
P3	130	150	1.00	High
P4	140	150	1.00	High
P5	120	140	0.67	Moderate
P6	110	150	1.00	High
P7	150	140	N/A	Decreased (ceiling at pretest)
P8	140	130	-1.00	Decreased
P9	100	120	0.40	Moderate
P10	120	150	1.00	High
P11	130	140	0.50	Moderate
P12	70	100	0.38	Moderate
P13	120	140	0.67	Moderate
P14	130	150	1.00	High

Note. N-Gain categories follow Hake (1999): High (≥ 0.7), Moderate (0.3–0.69), Low (< 0.3). Participant codes are anonymized and do not correspond to the order in which participants appear elsewhere in this manuscript.

Qualitative Analysis

Qualitative data were analyzed using the interactive model of Miles, Huberman, and Saldaña (2014), rather than a formal thematic analysis framework. The analysis involved three concurrent flows of activity: data reduction, data display, and conclusion drawing/verification, operationalized here as coding, categorization, theme development, and interpretation. Coding followed an inductive, open-coding approach: field notes, observation records, and participant reflections were read repeatedly, initial codes were generated close to the data, and related codes were grouped into categories that were iteratively refined into the themes reported below. Coding was performed by the author team through iterative discussion and consensus rather than by independent coders, so a formal inter-coder agreement statistic was not computed; this is noted as a limitation. Consistent with this approach, the two participants whose posttest scores declined relative to pretest (see Table 3) were deliberately examined alongside the dominant pattern of improvement, and the analysis

considers ceiling effects and testing fatigue as plausible explanations rather than treating the improvement pattern as uniform across all participants. Particular attention was given to themes related to eco-literacy development, environmental awareness, waste perception, and participants' understanding of circular economy principles.

Trustworthiness of the Findings

To enhance the credibility of the findings, data triangulation was conducted by comparing quantitative results with qualitative evidence obtained from observations, discussions, and participant reflections. The integration of multiple data sources enabled a more comprehensive understanding of how BSF cultivation contributed to eco-literacy development and circular economy education within the Maggotpreneur Program (Creswell & Plano Clark, 2018). Member checking, in which findings or interpretations are verified with participants themselves, was not conducted in this study; this is acknowledged as a limitation of the trustworthiness procedures used.

RESULTS AND DISCUSSION

Initial Assessment of Participants

Prior to the implementation of the Maggotpreneur Program, an initial assessment was conducted involving 53 learners enrolled in Package B and Package C equivalency education programs. The assessment aimed to identify participants' prior experiences and interests related to Black Soldier Fly (BSF) cultivation and entrepreneurship activities.

Table 2. Initial Assessment of Learners' Experience and Interests in the Maggotpreneur Program (N = 53)

Indicator	Yes	No	Percentage (Yes)
Previous experience in BSF cultivation	11	42	20.8%
Interest in BSF cultivation activities	25	28	47.2%

The findings indicate that only 20.8% of participants had previous experience with BSF cultivation, while 79.2% had never been involved in maggot cultivation activities. These results suggest that BSF cultivation represented a relatively new learning experience for most participants. Regarding learning interests, 47.2% of the 53 learners assessed expressed interest in BSF cultivation activities specifically. This finding indicates that although most learners lacked prior experience with BSF cultivation, a substantial share were interested in participating in practical, hands-on environmental learning activities.

The assessment results also reflect the characteristics of learners in nonformal education settings. As shown in Table 1, most participants had no prior experience with BSF cultivation (79.2%) before the program. Consequently, BSF cultivation provided a unique opportunity for participants to engage directly with environmental issues through hands-on learning experiences.

Improvement in Participants' Understanding of Circular Economy and Organic Waste Management

The quantitative findings indicate that participation in the Maggotpreneur Program contributed to improvements in learners' understanding of organic waste management, Black Soldier Fly (BSF) cultivation, and circular economy concepts. The pre-test and post-test results of the 14 participants in the BSF maggot cultivation learning group are presented in Table 3.

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Table 3. Pre-Test and Post-Test Results of BSF maggot cultivation learning group Participants (N = 14)

Indicator	Pre-Test	Post-Test	Remarks
Mean Score (/150)	122.1	138.6	+16.5
Mean Percentage	81.4%	92.4%	+11.0%
Minimum Score	70	100	+30
Maximum Score	150	150	–
Mean N-Gain	–	–	0.59 (Moderate)
Participants Improved	12 (85.7%)	–	–
Participants Decreased	2 (14.3%)	–	–

The results show an increase of 16.5 points between the pretest and posttest scores. As detailed in the Quantitative Analysis section above, this increase was statistically significant ($t(13) = 4.41$, $p < .001$) with a large effect size (Cohen's $d = 1.18$), and the average N-Gain score of 0.59 falls within the moderate category according to the classification proposed by Hake (1999). These findings suggest that BSF cultivation activities were associated with improvements in participants' understanding of environmental issues and circular economy concepts.

Although participants demonstrated relatively high initial knowledge levels, the intervention still produced measurable learning gains. This finding indicates that experiential and practice-based learning activities can strengthen environmental understanding even among learners who already possess basic knowledge regarding waste management. The improvement observed in this study supports the argument that experiential learning provides opportunities for learners to connect theoretical concepts with real-world experiences (Kolb, 1984). Through direct engagement in waste sorting, larval maintenance, feeding management, and harvesting activities, participants were able to observe firsthand how organic waste could be transformed into resources with environmental and economic value.

Eco-Literacy Development and Changing Perceptions of Organic Waste

Beyond measurable knowledge gains, qualitative findings revealed important developments in participants' eco-literacy. Prior to the program, many learners perceived organic waste primarily as a problem that should be discarded. Their understanding of waste management was generally limited to collection and disposal practices. The initial assessment showed that only 20.8% of participants had previous experience with BSF cultivation, indicating that most learners had limited exposure to practical environmental management activities. Consequently, participation in the Maggotpreneur Program provided a new learning experience that enabled learners to engage directly with environmental issues through hands-on activities.

During observations and group discussions, participants increasingly demonstrated awareness of the ecological relationships between waste generation, decomposition processes, and resource recovery. Through direct involvement in BSF cultivation, learners observed how organic waste could be converted into larval biomass and organic residue that could be reused for productive purposes. Verbatim participant quotations were not systematically recorded during the program's facilitator observations and are therefore not reported here; this reliance on summarized rather than directly quoted observational evidence is acknowledged as a limitation of the qualitative component.

These experiences contributed to the development of eco-literacy as defined by Orr (1992) and Capra (1999), who emphasize the importance of understanding ecological systems and recognizing the interdependence between human activities and environmental sustainability. Rather than learning about

environmental concepts solely through classroom instruction, participants engaged directly with ecological processes and observed the practical implications of sustainable waste management.

The findings are consistent with McBride et al. (2013), who argue that eco-literacy develops most effectively through authentic environmental experiences that encourage learners to engage with real-world environmental issues. In this study, BSF cultivation served as a contextual learning medium that connected environmental knowledge with practical action. A related shift observed within this same theme concerned participants' perceptions of organic waste. At the beginning of the program, several participants expressed discomfort and hesitation when introduced to BSF larvae. Many had never interacted with maggots before and initially associated them with dirt, unpleasant odors, or unsanitary conditions. This pattern was reported by facilitators based on observation rather than documented through verbatim quotations or systematic tracking of individual participants over time, so it is presented here as a general observational trend rather than a uniform or individually verified outcome; not all participants were confirmed to have moved past this initial discomfort by the end of the program.

This reaction is consistent with the initial assessment finding that most participants had no prior hands-on experience with BSF cultivation. Direct interaction with living organisms and waste-processing activities represented a new learning experience for many participants. As the program progressed, however, participants began to view organic waste differently. Rather than seeing waste solely as an environmental burden, they increasingly recognized its potential as a valuable resource. Through observation of the BSF life cycle and the conversion process, learners developed an understanding that waste could generate environmental and economic benefits when managed appropriately. This transformation reflects a key principle of circular economy education, which seeks to replace linear patterns of consumption and disposal with systems of resource recovery and regeneration (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Kirchherr et al., 2023). The findings suggest that BSF cultivation can provide a tangible demonstration of circular economy principles, enabling learners to understand abstract concepts through direct experience.

BSF Cultivation as a Contextual Learning Strategy in Nonformal Education

The findings also highlight the relevance of BSF cultivation as a contextual learning strategy within nonformal education settings. Nonformal education emphasizes flexibility, community relevance, and practical learning experiences that address real-life challenges (Rogers, 2005).

The Maggotpreneur Program engaged participants with a locally relevant environmental issue through hands-on BSF cultivation; this study examined only the environmental learning outcomes of the BSF maggot cultivation learning group and did not directly measure entrepreneurial competencies or economic benefits. The program's tagline, "Turning Waste into Blessings" (Mengubah Sampah Menjadi Berkah), captured the learning experience of participants, who—based on the qualitative evidence collected—gradually came to recognize organic waste as having environmental and, in their own perception, potential economic value.

The integration of environmental education, entrepreneurship, and experiential learning aligns with previous studies emphasizing the importance of participatory and contextual learning approaches in community-based education programs (Ratnasari et al., 2021). However, this study extends previous research by demonstrating how direct involvement in BSF cultivation contributes specifically to eco-literacy development and circular economy education among learners in nonformal education settings.

The moderate N-Gain score, combined with qualitative evidence of changing perceptions and increased environmental awareness, suggests that BSF cultivation holds promise as an educational strategy for promoting sustainable thinking and environmental responsibility; confirming its effectiveness, however, will require studies with comparison groups. The findings indicate that learning activities centered on real environmental challenges can encourage learners not only to acquire knowledge but also to develop new ways of understanding their relationship with waste and the environment.

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LIMITATIONS

This study has several limitations that should be considered when interpreting its findings. First, the quantitative component used a one-group pretest–posttest design without a comparison or control group, which precludes causal claims about the effectiveness of BSF cultivation; observed gains may be partly attributable to maturation, testing effects, or concurrent classroom instruction rather than the intervention alone. Second, the sample was small (n = 14), drawn from participants who voluntarily joined the BSF maggot cultivation learning group based on interest rather than random assignment, which limits statistical power and the generalizability of the findings beyond this specific group and site. Third, the study was conducted at a single PKBM over a relatively short three-week period, and longer-term retention of learning gains was not assessed. Fourth, several participants entered the program with relatively high pretest scores, and one participant began at the maximum possible score; this ceiling effect likely constrained the measurable gains for these participants and may partly explain the two cases in which posttest scores were lower than pretest scores. Fifth, the 15-item knowledge instrument was developed by the program facilitators and mapped to the intervention's learning indicators, but it did not undergo formal content-validity or reliability testing, so its psychometric properties are unknown. Sixth, claims regarding entrepreneurship competencies and economic benefits were not directly measured in this study and are therefore not asserted as findings. Seventh, because eco-literacy encompasses attitudes, awareness, skills, and actions in addition to knowledge, and the instrument used here primarily measured the knowledge component, claims about developing eco-literacy as a whole are limited accordingly. Eighth, member checking with participants was not conducted, and qualitative coding was performed by the author team through discussion rather than by independent coders with a formal inter-coder agreement statistic. Given these limitations, the study is best understood as an exploratory case study that generates context-specific, hypothesis-generating insight into how BSF cultivation may support eco-literacy and circular economy learning, rather than as confirmatory evidence of program effectiveness. Future research employing comparison groups, larger and more diverse samples, longer intervention and follow-up periods, and validated entrepreneurship measures is needed to test these preliminary findings.

CONCLUSION

This exploratory mixed-methods case study investigated the use of Black Soldier Fly (BSF) cultivation as a strategy for eco-literacy development and circular economy education in a nonformal education setting through the Maggotpreneur Program at PKBM Bhina Swakarya. The findings indicate that participation in BSF cultivation activities was associated with improvements in learners' understanding of organic waste management, environmental sustainability, and circular economy concepts, as reflected by a moderate mean N-Gain score of 0.59 and a large paired effect size (Cohen's d = 1.18); given the one-group design and small sample, this association should be interpreted as preliminary rather than causal evidence of effectiveness. Beyond cognitive improvement, the program contributed to the development of eco-literacy by enabling participants to directly experience ecological processes and resource recovery practices. Learners gradually shifted their perceptions of organic waste from viewing it as a problem to recognizing it as a resource with environmental and economic value. These findings underscore the potential value of experiential and contextual learning approaches in promoting meaningful environmental education within nonformal education settings, warranting further confirmatory research. The study contributes to the literature by positioning BSF cultivation not only as a waste management technology but also as an educational medium for eco-literacy development and circular economy learning. Future research may involve larger participant groups, longer intervention periods, and comparative studies across different educational contexts to further examine the educational impacts of BSF-based learning programs.

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