



Integration of Sustainable Environmental Education through a Digital Waste Incentive System

(A Study of Its Impact on Students' Ecological Literacy)

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Abstract. This study aims to analyze the impact of integrating sustainable environmental education through a digital waste incentive system on students' ecological literacy, covering cognitive, affective, and behavioral dimensions. The study was designed as a quasi-experiment using a non-equivalent control group pretest-posttest design with a delayed posttest. The participants were 72 eighth-grade students divided into experimental and control groups. The experimental group received science/Pancasila student profile project-based environmental learning integrated with the Plastic-to-Grocery system, a digital platform that records students' plastic waste deposits through QR/student identification numbers, converts deposits into points, and provides feedback through a dashboard. The control group received conventional environmental learning through lectures, posters, discussions, and reflective assignments. The instruments included a cognitive test, ecological attitude scale, observation sheet, and digital log of waste-deposit behavior. The sample analysis shows that the experimental group achieved N-gain scores of 0.45 for cognitive, 0.33 for affective, and 0.47 for behavioral aspects, higher than the control group with 0.22, 0.17, and 0.12, respectively. Statistical tests indicated significant differences across all three dimensions. These findings suggest that a digital waste incentive system has the potential to bridge the gap between environmental knowledge and ecological action by providing real-world experience, instant feedback, social reinforcement, and objective behavioral records.

Keywords: Digital Incentive; Ecological Literacy; Plastic Waste; Pro-Environmental Behavior; Sustainable Environmental Education.

1. INTRODUCTION

Environmental education in the 21st century is no longer sufficiently understood as an activity that merely conveys information about pollution, biogeochemical cycles, or the dangers of single-use plastics. Within the framework of education for sustainable development, schools are required to develop learners who are able to understand ecological systems, make decisions, and act responsibly toward environmental problems. Through the Education for Sustainable Development for 2030 framework, UNESCO emphasizes five priority action areas: policy, transforming learning environments, building the capacity of educators, empowering youth, and accelerating local-level action (UNESCO, 2020). In line with this, the UNESCO green school standard underscores the importance of integrating sustainability into school governance, facilities and operations, learning, and community engagement (UNESCO, 2024).

In this context, science education holds a strategic position because it can connect scientific knowledge with real actions in students' surrounding environment. Ecological literacy refers to the ability to understand the organizing principles of ecosystems and to use those principles in everyday life to build sustainable communities (Clavin, 2014). McBride et al. (2013) show that the terms environmental literacy, ecological literacy, and ecoliteracy are often used in diverse ways, but their commonality lies in the need to connect ecological knowledge,

dispositions, skills, and behavior (McBride et al., 2013). Thus, the success of environmental education cannot be measured only by students' ability to answer questions about types of waste, but also by their concern, responsibility, and concrete actions in managing waste.

The urgency of strengthening ecological literacy is increasing because waste, especially plastic waste, remains a serious issue in Indonesia. Indicative data from the National Waste Management Information System in 2025 show waste generation of 29,197,599.98 tons per year from 278 reporting regencies/cities, with 32.9% managed waste and 67.1% unmanaged waste (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, 2020). The World Bank report on plastic waste in Indonesia also emphasizes that local waste management practices contribute to the leakage of plastic waste into rivers and coastal areas (World Bank Group, 2021). These data show that waste management is not only a technical matter of collection, sorting, or recycling, but also a matter of education, habits, and ecological behavior from school age onward.

At the school level, a frequently emerging problem is the gap between knowledge and action. Students may state that plastic waste is harmful, but they do not necessarily sort waste, bring drinking bottles, reduce single-use plastics, or consistently collect plastic for recycling. Research by Nisa et al. (2025) in secondary schools in Tangerang shows that positive attitudes toward waste management do not always turn into active involvement; this condition indicates an attitude-behavior gap in school waste management practices. This kind of gap is a major challenge for environmental education, because learning that merely adds information does not necessarily produce ecological action (Nisa et al., 2025a).

Conventional methods such as lectures, posters, and cleanliness slogans can indeed increase initial awareness, but they often do not provide repeated, measurable, and meaningful behavioral experiences. The environmental literacy assessment framework emphasizes that measurement should include knowledge, skills, dispositions, and behavior (Hollweg et al., 2011a). In addition, the study by Orlovic Lovren and Marusic Jablanovic (2023) shows that environmental education learning outcomes still tend to be dominated by cognitive aspects, while affective and behavioral dimensions often receive insufficient attention (Lovren & Jablanovic, 2023). This indicates the need for a learning approach that not only explains environmental problems, but also facilitates students in carrying out real ecological actions.

Today's generation of students lives in a digital culture accustomed to rapid feedback, visualization of achievements, application-based interaction, and point systems. Cheng et al. (2022) show that gamification can serve as a driver of motivation and recycling intention among adolescents (Cheng et al., 2022). In the field of waste management, technologies such as reverse

vending machines and incentive-based systems have also been increasingly studied because they can connect user behavior with rewards and data recording. Zia et al. (2022) developed an incentive-based reverse vending machine to collect, identify, classify, and sort plastic bottles using a reward application (Zia et al., 2022). Fernandes and Maurício C. (2025) also show that reverse vending machines and deposit refund systems are important instruments in the circular economy, although their role in interdisciplinary research still needs to be developed (Fernandes & Maurício C., 2025).

In Indonesia, the Independent Curriculum through the Pancasila Student Profile Strengthening Project (P5) provides strong space for real-problem-based environmental education. The P5 guide emphasizes that a project is cross-disciplinary collaborative learning for observing, exploring, and formulating solutions to real issues that are relevant to learners (Aditomo, 2024). Therefore, the integration of a digital waste incentive system into science learning or P5 is not merely a technical innovation in waste management, but also a pedagogical strategy for building ecological literacy through direct experience, behavioral reinforcement, scientific reflection, and school community involvement.

Based on this gap, this study develops and tests a Plastic-to-Grocery-based digital waste incentive system. This system enables students to deposit sorted plastic waste, scan their identity, earn digital points, view ecological contributions through a dashboard, and redeem points for learning needs or limited cooperative vouchers. The novelty of this study lies in three aspects. First, the intervention does not only measure knowledge, but also affective and ecological behavior dimensions. Second, behavior is measured not only through questionnaires, but also through digital logs of waste deposit frequency. Third, environmental learning is combined with incentive technology and pedagogical reflection so that students are not only informed about the importance of managing waste, but also directly experience the relationship between action, impact, and ecological responsibility.

The research problem of this study is: does the integration of sustainable environmental education through a digital waste incentive system have a significant impact on students' ecological literacy in cognitive, affective, and behavioral aspects. Specifically, this study examines the improvement of students' knowledge of plastic types and their impacts, the improvement of ecological concern and responsibility, and the increase in the frequency of behavior involving bringing and depositing waste into the digital incentive system.

2. THEORETICAL REVIEW

Sustainable Environmental Education

Sustainable environmental education aims to develop learners' knowledge, attitudes, skills, and behaviors so that they are able to understand environmental problems and take responsible actions toward sustainability. Within the *Education for Sustainable Development (ESD) 2030* framework, UNESCO emphasizes the transformation of learning environments, educator capacity building, youth empowerment, and local-level action (UNESCO, 2020). Therefore, environmental education should not be limited to transferring knowledge but should provide learners with opportunities to experience and practice sustainable actions.

Science education has an important role in this process because scientific concepts related to ecosystems, pollution, and waste management can be connected to real environmental problems. Project-based learning can further strengthen this connection by engaging learners in investigating and responding to authentic problems. In Indonesia, the *Projek Penguatan Profil Pelajar Pancasila* (P5) provides opportunities for learners to explore real-world issues through collaborative and interdisciplinary learning (Aditomo, 2024). Thus, environmental learning can serve as a context for developing knowledge as well as meaningful environmental action.

Ecological Literacy

Ecological literacy refers to the ability to understand the organizing principles of ecosystems and apply them in everyday life to support sustainable communities (Clavin, 2014). McBride et al. (2013) explain that although the terms *environmental literacy*, *ecological literacy*, and *ecoliteracy* have been defined in different ways, they share an emphasis on connecting ecological knowledge, dispositions, skills, and behavior.

In this study, ecological literacy is examined through three dimensions: cognitive, affective, and behavioral. The cognitive dimension refers to learners' knowledge and understanding of plastic waste and its environmental impacts. The affective dimension concerns environmental concern, awareness, and responsibility. The behavioral dimension concerns concrete actions in managing plastic waste, particularly collecting and depositing plastic waste through the waste management system. This multidimensional approach is consistent with the view that environmental literacy should encompass knowledge, skills, dispositions, and behavior (Hollweg et al., 2011b).

Digital Incentive Systems and Pro-Environmental Behavior

Knowledge and positive environmental attitudes do not always lead to consistent environmental behavior. Nisa et al., (2025) found that positive attitudes toward waste management were not necessarily accompanied by active involvement in school waste

management practices. This gap indicates the need for learning experiences that provide opportunities for direct environmental action and continuous feedback.

Digital incentive systems may provide such opportunities by connecting environmental actions with activity records, feedback, and rewards. (Cheng et al., 2022) found that gamification can support motivation and recycling intention among adolescents. Similarly, Zia et al. (2022) demonstrated the potential of incentive-based technology to support plastic bottle collection and sorting through digital reward mechanisms. These findings suggest that digital systems can be integrated into environmental learning to strengthen engagement and encourage pro-environmental behavior.

In this study, the Plastic-to-Grocery system connects learners' plastic waste deposits with digital identification, points, dashboard feedback, and rewards. The system is integrated into project-based environmental learning so that learners experience a cycle of environmental knowledge → real-world action → digital feedback → reinforcement → reflection. Through this mechanism, the intervention is expected to connect environmental knowledge with concrete ecological behavior.

Previous Studies and Research Hypothesis

Previous studies have highlighted the importance of developing environmental literacy beyond the cognitive domain. Hollweg et al., (2011) emphasized the multidimensional nature of environmental literacy, while Lovren and Jablanovic (2023) reported that environmental education outcomes tend to emphasize cognitive aspects more strongly than affective and behavioral dimensions. Research on gamification and incentive-based waste management has also demonstrated the potential of digital mechanisms to encourage recycling motivation and (Cheng et al., 2022).

However, limited research has integrated project-based environmental education, a digital waste incentive system, and multidimensional ecological literacy assessment within a school context. The present study addresses this gap by examining cognitive, affective, and behavioral changes while using digital waste-deposit logs to complement conventional assessment instruments.

Based on the theoretical framework and previous research, the study hypothesizes that learners receiving sustainable environmental education integrated with the Plastic-to-Grocery digital incentive system demonstrate greater improvement in ecological literacy than learners receiving conventional environmental education, particularly across cognitive, affective, and behavioral dimensions.

3. METHOD

Research Design

This study used a quasi-experimental design of the non-equivalent control group pretest-posttest type with a delayed posttest. This design was chosen because the study was conducted in existing classes at the school, making individual randomization difficult. The experimental group received sustainable environmental learning integrated with a digital waste incentive system, while the control group received conventional environmental learning in the form of lectures, discussions, posters, and reflective assignments. The delayed posttest was conducted four weeks after the posttest to examine the persistence of students' ecological behavior.

Table 1. Research Design.

Group	Pretest	Treatment	Posttest	Delayed posttest
Experimental	O1	Science/P5 learning + digital waste incentive system	O2	O3
Control	O1	Conventional environmental learning	O2	O3

Note. O1 = initial measurement; O2 = measurement after the intervention; O3 = retention measurement four weeks after the intervention

Research Subjects and Location

The research subjects were 72 eighth-grade students at one MTs in Pati Regency, namely MTs Madrasatul Qur'an Salafiyah. Two classes were selected as research classes, each consisting of 36 students for the experimental group and 36 students for the control group. Class selection was carried out using cluster sampling based on the equivalence of learning schedules, subject teachers, and initial academic characteristics. In the final manuscript, this section needs to be completed with the region name, school characteristics, numbers of male and female students, condition of waste management facilities, and initial observation data on waste-sorting behavior.

The study was conducted over six weeks of intervention and four weeks of retention observation. In the first week, the researcher administered the pretest, conducted initial observations of waste management behavior, and provided technical socialization of the system. Weeks two to five were used for learning implementation and waste-deposit practice. The sixth week was used for the posttest, while the delayed posttest was conducted four weeks after the posttest.

Description of the Plastic-to-Grocery System

The system developed was named the Plastic-to-Grocery Digital Incentive System. This system consists of four main components: a user identification module through QR codes or student identification numbers, a module for recording plastic waste deposits based on type and weight/quantity, a points module that converts valid waste into digital points, and a feedback

dashboard that displays the number of deposits, estimated weight of collected plastic, class contributions, and point redemption status.

Points are not positioned merely as economic rewards, but as behavioral reinforcement and a medium for reflection. Point redemption is limited to school cooperative vouchers, stationery, learning needs, and various light snacks. This limitation is important so that the intervention does not turn environmental education into a purely economic transaction. Each waste deposit is verified by an operator/accompanying teacher based on criteria for plastic type, cleanliness, and sorting accuracy.

Intervention Procedure

Table 2. Intervention Implementation Plan.

Week	Experimental group activities	Control group activities	Data collected
1	Pretest, initial observation, digital system orientation	Pretest, initial observation, material orientation	Initial cognitive, affective, and behavioral scores
2	Material on plastic types, recycling symbols, and microplastic impacts	Lecture and discussion on plastic types	Student worksheet
3	Sorting practice and deposit simulation via QR/NISN	Poster and reflection assignment	Observation of sorting accuracy
4	Scheduled waste deposits and class dashboard reflection	Class cleanliness campaign	Deposit log and reflection notes
5	Reinforcement of the Plastic-to-Grocery project and circular economy discussion	3R discussion and homework	Deposit log and observation
6	Posttest and brief interview	Posttest and brief interview	Posttest score
7	Delayed posttest and retention log download	Delayed posttest and retention observation	Retention score and follow-up behavior

Operational Definitions and Instruments

Ecological literacy in this study is defined as students' ability to understand plastic waste issues, demonstrate ecological concern and responsibility, and carry out real actions in the form of bringing, sorting, and depositing plastic waste through a digital incentive system. This definition is operationalized into three aspects: cognitive, affective, and psychomotor/behavioral.

Table 3. Operational Definition of Ecological Literacy.

Aspect	Operational definition	Indicators	Instrument	Score
Cognitive	Students' knowledge of plastic waste, plastic types, ecological impacts, and recycling principles	Identifying PET, HDPE, and PP; explaining plastic impacts; understanding 3R and the circular economy	20-item multiple-choice test	0-100
Affective	Students' concern, responsibility, and commitment to waste management	Sense of concern, personal responsibility, ecological norms, willingness to participate	15-item Likert scale	0-100
Psychomotor/ Behavior	Students' actual behavior in bringing, sorting, and depositing plastic waste	Deposit frequency, sorting accuracy, retention consistency	Digital log and observation sheet	Frequency/4 weeks and normalized score

Instrument Validity and Reliability

The cognitive instrument was validated through expert judgment by science education experts, environmental experts, and learning evaluation experts. Content validity was analyzed using Aiken's V. Cognitive test items were tested through difficulty level, discrimination index, and KR-20 reliability. The affective instrument was tested using construct validity and Cronbach's alpha reliability. Behavioral data were validated through consistency between digital logs, operator verification, and teacher observations.

In the final manuscript, validity and reliability values need to be reported based on the actual instrument testing results. The following table is provided as a reporting format, not as final data.

Table 4. Instrument Validity and Reliability Reporting Format.

Instrument	Type of validity/reliability	Reporting criteria	Value in the final manuscript
Cognitive test	Content validity and KR-20	Aiken's V, difficulty level, discrimination index, KR-20	[fill in based on actual data]
Affective scale	Content/construct validity and Cronbach's alpha	Aiken's V, item-total correlation, alpha	[fill in based on actual data]
Behavioral observation	Inter-rater reliability	Cohen's kappa or percentage agreement	[fill in based on actual data]
Digital log	System validation and operator verification	Consistency of logs with deposit evidence	[fill in based on actual data]

Data Analysis Techniques

Data were analyzed using descriptive and inferential statistics. Score improvement was calculated using N-gain with the formula: $N\text{-gain} = (\text{posttest score} - \text{pretest score}) / (\text{maximum score} - \text{pretest score})$. N-gain was used to compare pretest-posttest score improvements, particularly in educational research using intervention designs (Hake, 1998).

Normality was tested using Shapiro-Wilk and homogeneity using Levene's test. Differences in cognitive and affective improvement were analyzed using an independent t-test if parametric assumptions were met, while behavioral data in the form of frequencies were analyzed using the Mann-Whitney U test. To strengthen the conclusions, ANCOVA was used with posttest scores as the dependent variable, group as the independent variable, and pretest scores as the covariate. Effect sizes were reported using Cohen's d, rank-biserial correlation, and partial eta squared according to the type of analysis.

4. RESULT AND DISCUSSION

Equivalence of Initial Ability

The results of the initial equivalence test showed that there were no significant differences between the experimental and control groups in cognitive, affective, or behavioral aspects. Thus, the two groups can be considered to have relatively equivalent initial conditions before the intervention.

Table 5. Equivalence of Initial Scores Between the Experimental and Control Groups.

Aspect	Experimental (M +/- SD)	Control (M +/- SD)	t	p
Cognitive	54,80 +/- 8,99	56,71 +/- 7,29	-0,99	0,326
Affective	60,99 +/- 5,79	60,97 +/- 6,43	0,01	0,991
Behavior	1,22 +/- 1,22	1,00 +/- 0,72	0,94	0,350

Comparison of Pretest, Posttest, Retention, and N-gain Scores

Table 6. Comparison of Ecological Literacy Scores Between Groups.

Aspect	Group	Pretest	Posttest	Retention	N-gain
Cognitive	Experimental	54,80 +/- 8,99	74,44 +/- 10,55	72,05 +/- 11,91	0,45 +/- 0,16
Cognitive	Control	56,71 +/- 7,29	65,93 +/- 9,28	62,70 +/- 9,95	0,22 +/- 0,12
Affective	Experimental	60,99 +/- 5,79	73,91 +/- 7,52	72,74 +/- 7,91	0,33 +/- 0,17
Affective	Control	60,97 +/- 6,43	67,67 +/- 7,59	65,01 +/- 9,60	0,17 +/- 0,13
Behavior	Experimental	1,22 +/- 1,22	6,42 +/- 2,20	5,94 +/- 2,54	0,47 +/- 0,21
Behavior	Control	1,00 +/- 0,72	2,36 +/- 1,33	1,89 +/- 1,45	0,12 +/- 0,13

The sample data show that the experimental group experienced greater improvement in all aspects of ecological literacy. The largest improvement appeared in the behavioral aspect because the digital system provided students with opportunities to carry out ecological actions repeatedly, in a verified and recorded manner.

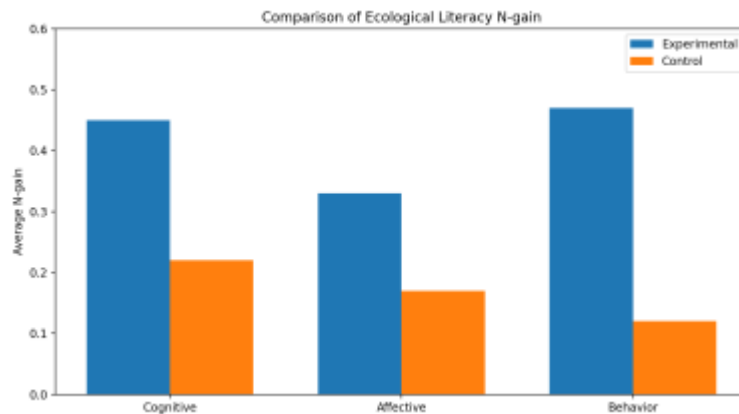


Figure 1. Comparison of Ecological Literacy N-gain in the Experimental and Control Groups. *Note. The figure was created from sample/simulated data. Replace it with visualization of actual data before submission.*

Statistical Test Results

Table 7. Results of the N-gain Difference Test and ANCOVA.

Aspect	N-gain test	p	Effect size	ANCOVA posttest controlling for pretest
Cognitive	t (70) = 6,81	<0,001	d = 1,60	F (1,69) = 62,09; eta_p^2 = 0,47
Affective	t (70) = 4,52	<0,001	d = 1,07	F (1,69) = 22,09; eta_p^2 = 0,24
Behavior	U = 1219,5	<0,001	r rb = 0,88	F (1,69) = 86,98; eta_p^2 = 0,56

The analysis results showed significant differences between the experimental and control groups in cognitive, affective, and behavioral aspects. The effect size values for the three aspects were in the strong category. The ANCOVA results also showed that, after controlling for pretest scores, the experimental group still had higher posttest scores than the control group.

Digital Waste Incentive System Log Data

Table 8. Summary of Waste Management Behavior Log.

Log indicator	Experimental	Control	Notes
Number of valid deposits	231 times	85 times	System/observation log data
Mass of plastic collected	4 kg	1 kg	Weekly weighing
Sorting accuracy	86,76%	70,25%	Rubric + operator verification
Estimated PET bottles/packages	413 items	-	From system validation log
Accumulated points	4,065 points	-	5 points/valid item; exchanged for cooperative vouchers

The log data show that students in the experimental group not only obtained higher knowledge scores, but also demonstrated stronger behavioral engagement. Digital logs serve as objective evidence that can strengthen the study's claims because students' behavior was not measured only through questionnaires.

The results of the study show that the integration of a digital waste incentive system can improve students' ecological literacy multidimensionally. In the cognitive aspect, the increased scores of the experimental group indicate that students more easily understood plastic types, recycling symbols, and ecological impacts when science material was linked to direct practice. Learning did not stop at the concept that plastic is harmful, but moved toward an understanding of plastic types, sorting flows, reuse value, and the ecological consequences of daily actions. This finding is in line with the idea of ecological literacy as the ability to understand the organizing principles of ecosystems and use them to build sustainable communities (Clavin, 2014).

In the affective aspect, the increased scores of the experimental group show that the digital system served as a medium for internalizing ecological responsibility. A dashboard displaying the amount of waste collected, class contributions, and student points made ecological actions visible, measurable, and appreciated. This is relevant to the study by Orlovic Lovren and Marusic Jablanovic (2023), which emphasizes the importance of bridging cognitive, affective, and behavioral dimensions in environmental education. Environmental education that overemphasizes cognitive aspects may produce students who know, but do not necessarily care and act.

In the behavioral aspect, the clearest differences were seen in waste deposit frequency and sorting accuracy. This finding strengthens the argument that digital systems can serve as a bridge between knowledge and action. In conventional learning, students may understand that

littering is a bad action, but they do not have a routine mechanism that encourages them to perform alternative actions. The digital incentive system provides such a mechanism through ease of action, instant feedback, log recording, and social reinforcement. The study by Cheng et al. (2022) also shows that a gamification approach can improve recycling attitudes and intentions among adolescents because recycling activities that were previously considered monotonous can be packaged as a more interactive experience (Cheng et al., 2022).

The novelty of this study lies in the integration of environmental education, incentive technology, and log-based behavioral assessment. Many school environmental programs stop at campaigns, posters, or cleanliness competitions, while this study positions students' behavior as data that can be recorded and analyzed. This approach aligns with the direction of green school development because it connects learning, school facilities, governance, and community engagement (UNESCO, 2024). In other words, the Plastic-to-Grocery system is not only a waste collection device, but also an ecological learning infrastructure.

The results of this study are also relevant to the development of P5 under the theme of sustainable lifestyles. The digital waste incentive system can become a medium for cross-disciplinary projects: science discusses plastic types and their impacts; mathematics processes deposit data; informatics reads digital logs; social studies discuss the circular economy; and Pancasila education discusses the responsibilities of school citizens. Thus, this system can function as a school ecological laboratory that connects concepts, values, and real actions. This framework is in line with the P5 Guide, which emphasizes cross-disciplinary collaborative learning to explore solutions to real problems (Hake, 1998).

Nevertheless, the retention results show a slight decrease in scores and behavioral frequency after the intervention ended. This is academically important because it indicates that digital incentives are not a single solution. For behavior to persist, incentives must be combined with value reflection, social norms, teacher support, adequate sorting facilities, and school culture. If incentives are understood only as rewards, ecological behavior risks weakening when the rewards are stopped. Therefore, Plastic-to-Grocery needs to be designed not merely as a waste-points transaction, but as a learning ecosystem that connects students' actions with ecological understanding and social responsibility (United Nations Environment Programme, 2026).

Compared with waste management literacy studies that generally use knowledge, attitude, and behavior models through surveys, this study adds a digital log component as evidence of actual behavior. This is important because Nisa et al. (2025) found a gap between positive attitudes and active involvement in school waste management. Thus, the contribution of this

study is to offer an intervention model that not only measures that gap, but also attempts to bridge it through technology design and action-based learning (Nisa et al., 2025a).

5. CONCLUSIONS

The integration of sustainable environmental education through a digital waste incentive system has the potential to improve students' ecological literacy in cognitive, affective, and behavioral aspects. The Plastic-to-Grocery system helps students understand the types and impacts of plastic waste, increase ecological concern and responsibility, and encourage real action in the form of sorted waste deposits. The main strength of the intervention lies in the combination of direct experience, instant feedback, objective behavior recording, and learning reflection. These findings affirm that effective environmental education cannot rely solely on lectures or posters, but needs to provide a system that enables students to experience, record, reflect on, and repeat ecological actions. For further research development, multi-school trials, longer retention periods, cost-benefit analyses, and testing of whether behavior persists after incentives are reduced or discontinued are needed.

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