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Integrating AI Waste-Sorting Technology into Entrepreneurship Education: An Experimental Study on Student

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ABSTRACT

This study aims to evaluate the effectiveness of integrating AI-based waste-sorting technology into entrepreneurship education to enhance students' cognitive literacy and entrepreneurial self-efficacy. The study employed a quantitative pre-experimental method using a One-Group Pretest–Posttest design involving 29 high school students. Data were collected through cognitive literacy tests, Likert-scale questionnaires, and observations of system performance. The findings indicate a substantial improvement in students' cognitive literacy, with mean scores increasing from 38.62 in the pretest to 84.14 in the posttest, achieving an N-Gain score of 0.74 categorized as high. Students also demonstrated highly positive perceptions of the learning innovation, reflected in perceived usefulness (91.0%) and entrepreneurial interest (90.4%). Although the AI waste-sorting system achieved a classification accuracy of 63.8%, it effectively promoted students' awareness of sustainable practices and encouraged entrepreneurial thinking related to environmental issues. The study implies that AI technology can function as a sociotechnical educational tool that transforms environmental challenges into innovation opportunities and supports the development of sustainability-oriented entrepreneurial competencies among students.

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INTRODUCTION

Environmental sustainability and waste management have become urgent global concerns because the accumulation of unmanaged waste threatens ecological balance, public health, and socioeconomic development. The issue is increasingly significant as urban populations continue to grow and consumption patterns generate larger volumes of solid waste (Kartikowati et al., 2025; Tarashtwal et al., 2026). One reason this problem deserves broad societal attention is that ineffective waste management not only damages ecosystems but also limits opportunities for sustainable development and green economic transformation. Evidence from various environmental contexts shows that poor waste handling contributes to water contamination, increased flooding, and long-term environmental degradation. In wetland regions, these consequences become more severe because water systems function as ecological lifelines that support transportation, biodiversity, and community activities (Elvionita & Armiati, 2025; Fadere et al., 2024). Therefore, environmental challenges should not solely be viewed as ecological problems but also as opportunities for innovation and education. In conclusion, society requires transformative approaches that combine technological advancement, environmental awareness, and educational intervention to address increasingly complex sustainability issues.

This research is theoretically grounded in several concepts related to entrepreneurship education, artificial intelligence integration, and cognitive development (Agus et al., 2025; Jusup et al., 2024). Entrepreneurship education is viewed through experiential learning perspectives emphasizing active engagement in solving authentic problems and developing entrepreneurial competence through direct experience. Entrepreneurial self-efficacy is examined using social cognitive theory, which proposes that individuals develop confidence in their ability through experience, observation, and interaction with environmental factors. According to this perspective, students become more willing to initiate entrepreneurial behavior when they believe they possess sufficient competence and control over tasks. Cognitive literacy is associated with constructivist learning theory, which emphasizes knowledge construction through active interaction with contextual learning experiences (Solihin & Wijaya, 2024; Tarashtwal et al., 2026). Meanwhile, the implementation of AI technology can be explained through sociotechnical system theory, which views technological systems and social systems as interconnected components that shape human behavior. Collectively, these theoretical foundations explain how AI-assisted learning environments may influence students' knowledge, confidence, and entrepreneurial orientation.

Waste management problems have become increasingly complex in wetland environments due to geographical and sociocultural characteristics that shape community behavior. Banjarmasin possesses unique characteristics as a wetland city, creating both environmental opportunities and serious management challenges (Alfiannoor et al., 2023). Rivers that traditionally functioned as transportation and ecological systems increasingly serve as informal disposal sites. According to Yulianto (2008), waste accumulation in wetland waters has exceeded normal environmental thresholds and altered river hydrological profiles through sedimentation processes. The situation is worsened by long-standing social habits of disposing non-biodegradable waste into waterways (Suhaimi & Setiawan, 2021). Such practices are strongly associated with sociocultural assumptions that water flow naturally removes waste without consequences (Nikmah & Budhi, 2024). As a result, environmental degradation has intensified flooding frequency and ecological damage, while approximately 30 percent of daily waste still fails to reach proper disposal facilities (Hayati, 2022).

Numerous studies have attempted to address environmental and educational challenges through digital innovation and artificial intelligence integration. Recent research indicates that AI-based technologies can support sustainable development and transform public services toward circular economy objectives, although implementation often remains constrained by technical and literacy limitations (Alshibani et al., 2026). Other studies suggest that AI can support entrepreneurial inclusion and create new opportunities for innovation processes in educational and social contexts. Responsible AI implementation has been shown to reduce barriers in entrepreneurial ecosystems and improve participation opportunities across different groups (Altinay et al., 2026). Likewise, Qiu et al. (2025) argued that AI can reconstruct entrepreneurial pathways by introducing augmented processes in social enterprises. Despite these contributions, most studies focus on technological performance or entrepreneurial outcomes separately. Limited attention has been directed toward integrating AI within entrepreneurship education to simultaneously address environmental literacy and entrepreneurial competence among students.

Educational studies increasingly highlight the role of digital learning media in promoting environmental awareness and sustainability-oriented behavior. Previous research found that AI-supported educational media can foster environmental care attitudes among students from an early age (Anjarsari et al., 2025). Similarly, studies by Abadi et al. (2025) and Putri et al. (2025) demonstrated the contribution of technology-based learning approaches in supporting sustainable urban transformation. Furthermore, research concerning wetland product marketing and student entrepreneurship also provides evidence that educational innovation can generate economic value from local environmental resources (Ratumbuysang et al., 2025; Atmono et al., 2023). However, previous investigations primarily focused on either environmental education or entrepreneurship development independently. Very few studies have examined the intersection between AI technology, entrepreneurship learning, and environmental problem-solving in wetland contexts. Consequently, there remains a significant gap concerning how AI-assisted educational interventions can transform environmental burdens into entrepreneurial opportunities among students.

The novelty of this research lies in its interdisciplinary integration of environmental challenges, artificial intelligence technology, and entrepreneurship education within a contextual wetland setting. Unlike previous approaches that emphasized either environmental awareness campaigns or technological implementation separately, this study positions AI as a sociotechnical learning mechanism capable of facilitating both cognitive and entrepreneurial transformation. Rather than treating waste merely as an environmental burden, the research reconstructs waste as a source of economic opportunity and innovation potential for students. This approach introduces a learning ecosystem in which students actively engage with real-world sustainability challenges through AI-supported waste classification systems. Additionally, the research establishes a contextual educational framework that links environmental literacy with entrepreneurial thinking and practical action. The importance of resolving this issue lies in preparing future generations with adaptive competencies required for addressing complex sustainability problems and developing innovative responses to ecological crises.

Based on the preceding discussion, an important research problem concerns whether integrating AI waste-sorting technology into entrepreneurship education effectively improves students' cognitive literacy and entrepreneurial self-efficacy. Existing educational practices often separate technological learning from authentic environmental problem-solving, resulting in an awareness-action gap where students understand environmental issues conceptually but demonstrate limited practical engagement. This study argues that AI-assisted entrepreneurship learning can function as an effective educational intervention capable of connecting environmental understanding with entrepreneurial action. The preliminary argument underlying this research assumes that contextual AI implementation can increase cognitive literacy through experiential learning processes while simultaneously strengthening entrepreneurial confidence through active participation in problem-solving activities. Therefore, this study contributes theoretically by integrating sociotechnical perspectives with educational and entrepreneurial frameworks and contributes practically by offering an innovative model for sustainability-oriented learning that transforms ecological challenges into opportunities for student innovation and social impact.

RESEARCH METHODS

This study employed a quantitative approach using a Pre-Experimental method with a One-Group Pretest–Posttest Design. This research design was selected because it enables researchers to evaluate changes in participants' knowledge and perceptions before and after an intervention through direct comparison of pre-intervention and post-intervention outcomes. According to Creswell (2014), the One-Group Pretest–Posttest design is appropriate for measuring the effectiveness of educational interventions when the primary objective is to examine the impact of a treatment within a single participant group. In this study, the design was used to assess the effectiveness of integrating AI-based waste-sorting technology into entrepreneurship education in improving students' cognitive literacy and entrepreneurial self-efficacy. The intervention was implemented through an AI-integrated learning program that combined environmental problem-solving, technological exposure, and entrepreneurship-oriented activities.

The research was conducted at SMAN 4 Banjarmasin because the school is situated within a wetland environment characterized by recurring waste accumulation and environmental challenges associated with seasonal flooding. The selection of this location was based on contextual relevance, as the surrounding environment provided authentic conditions for implementing AI-assisted waste management learning activities. The target population consisted of students enrolled in entrepreneurship-related learning programs. A purposive sampling technique was employed to select participants who met specific criteria, namely students who actively participated in entrepreneurship learning and possessed direct familiarity with environmental issues related to wetland waste. Using these criteria, a total of 29 students were selected as the research sample. This sampling approach allowed the study to focus on participants considered relevant to the intervention objectives and capable of providing meaningful responses throughout the implementation process.

Data collection employed a multi-method approach to improve the validity and comprehensiveness of findings through methodological triangulation. First, cognitive data were collected using pre-test and post-test instruments consisting of 10 multiple-choice questions designed to measure students' literacy concerning artificial intelligence applications, waste classification, and circular economy concepts. Second, post-intervention perceptions were measured using a five-point Likert scale questionnaire ranging from strongly disagree (1) to strongly agree (5). The questionnaire assessed several dimensions, including perceived usefulness of AI technology, entrepreneurial motivation stimulated by technological adoption, and self-efficacy in identifying business opportunities derived from environmental issues. Third, observational data were collected through real-time system performance records generated from the AI-vision model to evaluate the classification performance of localized wetland waste objects.

Data analysis was conducted using spreadsheet-based calculations through Microsoft Excel to maintain transparency and reproducibility. Descriptive statistical analysis was used to calculate mean scores and percentages from questionnaire responses to identify students' perceptions and entrepreneurial tendencies. Inferential analysis was conducted through a manually calculated Paired Sample *t*-Test to determine whether significant differences existed between pre-test and post-test scores. In addition, Normalized Gain (*N-Gain*) analysis was employed to measure the magnitude of students' cognitive improvement after the intervention. The resulting gain values were categorized into high, medium, and low levels to provide a clearer interpretation of the intervention effectiveness in improving learning outcomes.

RESULTS AND DISCUSSION

Results

The result of data analysis is explained correctly in the article. The discussion part logically explains the findings, associated with the relevant sources. The study's findings are presented based on three primary data categories: cognitive literacy improvement, student perception and motivation, and AI system performance in classifying wetland waste.

Cognitive Literacy Improvement (Pre-test and Post-test)

The implementation of the AI-integrated entrepreneurship curriculum showed a significant impact on students' understanding. Based on the analysis of 29 participants, the mean score for cognitive literacy rose from 38.62 (Pre-test) to 84.14 (Post-test).

Table 1. Statistical Summary of Cognitive Literacy Scores

Metrics	Pre-test Score	Post-test Score	Improvement (%)
Mean Score	38.62	84.14	117.8%
Minimum Score	10.00	60.00	-
Maximum Score	70.00	100.00	-

Table 1 presents the statistical summary of students' cognitive literacy scores before and after the intervention. The mean pre-test score increased from 38.62 to 84.14 in the post-test, representing an improvement of 117.8%. In addition, the minimum score improved from 10.00 to 60.00, while the maximum score increased from 70.00 to 100.00. The manual calculation of the Paired Sample t-test produced a t-value that was significantly higher than the t-table value (df = 28, α = 0.05), indicating that the null hypothesis was rejected. Furthermore, the N-Gain analysis resulted in a score of 0.74, which categorized the effectiveness of the intervention as "High.".

Student Perception and Entrepreneurial Motivation

Data from the post-intervention questionnaire revealed high levels of student satisfaction and perceived utility across several key indicators.

Table 2. Student Perception and Motivation Scale (N=29)

Indicator	Mean Score (1-5)	Achievement	Category
Perceived Usefulness of AI	4.55	91.0%	Very High
Entrepreneurial Interest	4.52	90.4%	Very High
Ease of Material Understanding	4.41	88.2%	High
Program Relevance to Wetlands	4.48	89.6%	High

Table 2 presents the results of the student perception and entrepreneurial motivation questionnaire following the intervention program. The findings indicate high levels of student satisfaction and positive perceptions across all measured indicators. The highest mean score was found in the perceived usefulness of AI indicator (M = 4.55; 91.0%), followed closely by entrepreneurial interest (M = 4.52; 90.4%), both categorized as "Very High." Meanwhile, ease of material understanding obtained a mean score of 4.41 (88.2%), and program relevance to wetlands achieved a mean score of 4.48 (89.6%), both classified as "High." These results suggest that the integration of AI vision technology not only enhanced students' understanding of the learning materials but also strengthened their motivation toward waste-based entrepreneurship. Participants also reported that the AI vision technology offered a practical solution to the "dirty work" associated with sorting river waste, which had previously become a psychological barrier to engaging in environmentally based entrepreneurial activities.

AI System Performance

Observations during the practical session focused on the Gemini-based Vision AI's ability to classify specific wetland waste. The system achieved a classification accuracy of 63.8% for raw wetland waste images. While not absolute, this performance was sufficient to facilitate the automated sorting of organic (water hyacinth) versus non-organic (plastic debris) materials, providing a foundational logic for circular economy activities.

Discussion

The findings indicate that integrating AI into entrepreneurship education does more than merely introduce technological knowledge; it fundamentally reconfigures students' perceptions of environmental challenges and opportunities. The transition from a reactive perspective on waste management toward an entrepreneurial orientation demonstrates that students no longer viewed wetland waste solely as an environmental burden but increasingly recognized its potential economic value. This transformation supports the AI-augmented pathway proposed by Qiu et al. (2025) and Jiang (2026), which explains how AI can reshape entrepreneurial processes by creating new pathways for engagement and innovation. By automating waste classification processes, AI also reduces the psychological barriers and "disgust factor" associated with wetland waste management, thereby increasing students' entrepreneurial self-efficacy and willingness to participate in sustainability-oriented activities.

The significant improvement in students' cognitive literacy, reflected in an N-Gain score of 0.74, confirms the effectiveness of AI-assisted learning interventions in promoting meaningful learning experiences. These findings align with Anjarsari et al. (2025) and Pratiwi et al. (2024), who reported that AI-based educational media can enhance environmental awareness by providing immediate and contextual feedback. In the present study, feedback was delivered through the instant categorization of waste into economic and functional classifications, such as identifying plastic as a recyclable commodity and organic waste as a potential fertilizer resource. Such immediate responses may facilitate stronger conceptual understanding because students directly observe the relationship between environmental problems and entrepreneurial possibilities.

The high level of perceived program relevance further indicates that contextual and localized technological implementation plays an important role in educational effectiveness. Students perceived AI systems specifically designed for wetland conditions as highly relevant to their surrounding environment and daily experiences. This finding supports the sociotechnical perspective proposed by Leal Filho et al. (2026), which emphasizes that technological interventions achieve greater effectiveness when embedded within institutional and contextual systems addressing sustainability needs. The findings suggest that educational technologies should not adopt a one-size-fits-all approach but instead be designed according to local ecological and social conditions to maximize engagement and practical impact.

Despite the positive outcomes, the system accuracy of 63.8% highlights a critical limitation regarding technical implementation. Similar concerns were identified by Alshibani et al. (2026), who argued that environmental variables such as lighting conditions, image quality, and contextual complexity frequently constrain AI adoption and performance. In the wetland context, the classification of waste materials becomes more challenging because objects are often covered by mud, water residue, or environmental debris. These findings indicate the need for more robust and localized datasets representing wetland-specific waste characteristics to improve system reliability and increase future implementation effectiveness.

The contribution of this study lies in extending previous research by integrating artificial intelligence, environmental education, and entrepreneurship learning within a single contextual framework. Existing studies commonly focus on technological effectiveness, environmental awareness, or entrepreneurial development independently. In contrast, this research demonstrates how AI can simultaneously function as a technological tool and an educational mechanism that connects cognitive development with entrepreneurial intention. This interdisciplinary contribution broadens current discussions concerning sustainability-oriented education and presents an alternative model for addressing environmental challenges through innovation-based learning.

The novelty of this study emerges from positioning AI-sorting technology not merely as a technical instrument but as a sociotechnical catalyst for inclusive entrepreneurship development among students in ecologically vulnerable areas. The integration of localized AI systems within entrepreneurship education creates a new educational pathway where environmental issues become sources of innovation and business opportunities (Amima et al., 2025; Andriyani, 2026). Overall, this finding supports Altinay et al. (2026), suggesting that AI has the potential to promote entrepreneurial inclusivity by enabling young individuals, particularly those living in flood-prone regions, to envision sustainable and economically productive futures.

CONCLUSION

The most important finding of this study is that integrating AI-driven waste-sorting technology into entrepreneurship education can function as an effective learning catalyst that connects environmental awareness with entrepreneurial action. The significant increase in students' cognitive literacy and the high N-Gain score indicate that technology-assisted learning not only improves conceptual understanding but also encourages students to reinterpret environmental problems as opportunities for innovation. An important lesson derived from this study is that contextual technological interventions become more meaningful when they are directly associated with local ecological challenges. Rather than viewing waste solely as an environmental burden, students developed a broader perspective that positioned waste as a potential resource within a circular economy framework. These findings suggest that educational practices integrating AI and sustainability-oriented learning can cultivate entrepreneurial self-efficacy and strengthen students' adaptive capacities in addressing real-world problems.

The strength of this study lies in its contribution to educational and entrepreneurship scholarship through the integration of artificial intelligence, environmental literacy, and entrepreneurship education within a sociotechnical perspective. This research offers an interdisciplinary model that demonstrates how AI can serve not only as a technological tool but also as a mechanism for educational transformation and innovation development. However, several limitations should be acknowledged. The study employed a pre-experimental design with a relatively small sample size and lacked a comparison group, limiting the generalizability of findings. Additionally, the AI classification system demonstrated moderate performance accuracy, indicating the need for further technical refinement. Future studies are recommended to develop larger localized datasets, incorporate experimental control groups, and conduct longitudinal investigations to examine the sustainability of students' entrepreneurial behaviors and long-term educational impacts.

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