Enhancing Campus Plastic Waste Management: Designing and Evaluating An AI-Powered Mobile Application with Gamification Features

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ABSTRACT

This study investigated the determinants of an artificial intelligence (AI)-driven mobile application and evaluated its capacity to enhance plastic waste management at a private university in Manila. Utilizing a descriptive research design and purposive sampling, data were collected from 207 students and 39 staff members during the second semester of the 2025–2026 academic year using a validated online instrument (Cronbach's alpha = 0.97). The findings revealed that while staff were fully familiar with plastic waste segregation, students were only somewhat familiar; both reported practicing segregation only sometimes and maintained a neutral initial stance toward AI and mobile application integration. However, both groups agreed that gamification features significantly enhance user motivation, and while staff agreed, students strongly agreed that the AI application contributes positively to institutional sustainability outcomes. Operational data from staff indicated that 10 to over 50 kg of plastic waste is collected weekly, primarily utilizing manual sorting and daily monitoring, with campaigns communicated via seminars. Although personnel identified existing systemic concerns, they concurred that the AI platform effectively optimizes the current waste management system, with both cohorts highly rating the application's technical features and expressing strong overall satisfaction with its real-world utility. Ultimately, this study provides empirical evidence supporting the integration of AI-enabled mobile software as a viable, sustainable mechanism to modernize solid waste management workflows in higher education institutions.

Keywords : Artificial intelligence, mobile application, plastic waste management, gamification, sustainability

INTRODUCTION

The global accumulation of plastic waste presents a severe environmental crisis, with higher education institutions serving as primary contributors due to widespread single-use plastics. Kaza et al. (2018) noted that while educational facilities are vital for demonstrating sustainable behavior, they simultaneously produce vast quantities of waste from daily disposables, food packaging, and laboratory consumables. Globally, a mere 9% of the 8.3 billion metric tons of plastic generated since the 1950s has been recycled (Geyer et al., 2017). This highlights the critical necessity for productive waste management frameworks within academic centers, which have the unique institutional capacity to shape long-term ecological habits.

Contemporary research points to incorporating sophisticated digital tools to correct systemic flaws in waste management. Certomà et al. (2024) observed that technology-driven interventions, particularly mobile applications combined with artificial intelligence (AI), are vital instruments for improving sorting precision, creating verifiable tracking systems, and boosting institutional recycling metrics. Mobile platforms can capture real-time disposal data through accessible methods such as QR code scanning and image uploads, allowing administrators to continuously improve recycling logistics. Simultaneously, AI systems process these digital data points to map waste generation patterns, delivering data-driven insights to guide campus sustainability policies.

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Although environmental compliance measures are increasingly common in tertiary education, existing frameworks face structural constraints. Carale et al. (2025) noted that campus recycling programs are regularly weakened by low participation rates, fragmented tracking, and an absence of instantaneous data monitoring. Achieving permanent behavioral adjustment requires institutions to actively involve students, faculty, and administrative staff in a unified ecological mission. Environmental awareness and stakeholder compliance can be systematically improved using interactive software and structured reward programs. Incorporating gamification principles into these applications sparks peer competition and personal success, turning waste segregation into an effortless habit within the campus routine.

In expansive private universities, catering to thousands of daily users produces a large and varied plastic waste stream extending from food services to scientific research labs. Even when recycling policies are officially established, institutional frameworks often suffer from poor user compliance, a lack of physical supervision, and low operational efficiency. Notably, existing academic literature has not explored these localized institutional vulnerabilities through the creation of a specialized mobile platform designed specifically for managing plastic waste inside a university ecosystem. Traditional campus strategies fail to deploy low-cost, readily available consumer electronics to organize plastic rubbish into four distinct administrative categories: residual, special, non-biodegradable, and biodegradable waste.

At present, there is a clear gap in the availability of integrated applications that provide synchronized tracking data and direct performance feedback to campus users. By merging machine learning with AI image classification, a specialized application can reduce sorting errors at disposal points while encouraging long-term user interaction through gamified point structures. This study aimed to describe the determinants of mobile application using artificial intelligence (AI) and its evaluation on enhancing school-wide plastic waste management

Furthermore, this technological endeavor directly advances multiple United Nations Sustainable Development Goals (SDGs). It supports SDG 4 (Quality Education) by integrating digital ecological literacy into the learning environment, and pushes forward SDG 9 (Industry, Innovation, and Infrastructure) by employing artificial intelligence to upgrade local institutional infrastructure. Additionally, it targets SDG 12 (Responsible Consumption and Production) by encouraging accountable sorting methods among campus stakeholders, while reinforcing SDG 13 (Climate Action) by lowering the localized carbon footprint and ecological damage associated with unmanaged institutional plastic pollution.

Objectives

- To describe the socio-demographic profile of university stakeholders and assess their levels of awareness and practices in plastic waste management, perceptions of AI and mobile applications in sustainability initiatives, perceptions of gamification and engagement features, and perceived sustainability outcomes of improved waste management practices.
- To determine the significant associations among awareness, practices, AI perception, gamification and engagement perceptions, sustainability outcomes, and institutional effectiveness.
- To describe the waste collection and institutional management perspective among janitorial staff, MRF operators, sustainability officers, and personnel directly involved in waste collection on campus.
- To identify the factors affecting proper plastic waste segregation within the campus environment.
- To describe the existing campaign strategies and institutional efforts implemented to promote waste segregation and sustainability on campus.
- To develop and evaluate an AI-powered mobile application with gamification features in terms of usability, plastic waste identification, gamification elements, engagement and behavior support, environmental awareness, technical performance, and overall user satisfaction.

METHODOLOGY

Research Design and Objectives

This study implemented a quantitative descriptive research design to describe the demographic characteristics of students and staff at a private university in Manila, alongside their baseline awareness, disposal habits, and attitudes toward integrating artificial intelligence, mobile applications, and gamification into campus plastic waste management. It also described frontline infrastructure workers—such as janitorial staff, Material Recovery Facility (MRF) operators, and sustainability officers—to identify structural barriers to waste segregation and critique existing campus eco-campaigns. Furthermore, the developed AI-powered platform was systematically described across several key performance markers, including structural usability, classification feature relevance, gamified reward components, behavioral prompts, technical performance, and overall user satisfaction.

Population, Samples, and Sampling Design

The target population consisted of university stakeholders directly involved in or affected by on-campus waste management protocols. Because exact institutional population data was restricted due to data privacy policies and localized time limitations, a purposive sampling approach was selected to capture information-rich respondents. The final sample size comprised 207 tertiary students and 39 academic and co-academic staff members, who were subsequently cross-classified by age, gender, academic department, and year level.

Data Collection Instruments

Empirical data collection was operationalized using three specialized survey instruments. The first tool, the Survey on Plastic Waste Management and AI-Based Mobile App Engagement, was distributed to students and staff to establish baseline data regarding recycling awareness, behavioral practices, and tech-driven sustainability expectations. The second instrument, the Waste Collection and Institutional Management Perspective Survey, focused on gathering data regarding physical processing realities from sustainability personnel and cleanup crews. The third tool, the App Evaluation Survey, was administered exclusively to pilot-test participants to evaluate real-world software usability, automated sorting accuracy, game mechanics, and technical performance. These instruments employed a standardized five-point Likert scale, where higher numerical values represented stronger agreement, familiarity, or satisfaction.

Validity and Reliability Testing

To preserve empirical validity, a panel of experts in solid waste management, machine learning development, and statistics appraised the questionnaires using the Good and Scates Validation Form. Subsequent pilot testing of the instruments within a comparable tertiary facility demonstrated a Cronbach's alpha value of 0.97, establishing excellent internal consistency and confirming instrument reliability.

Development of Mobile Application

A prototype mobile application designed to assist waste management procedures was created as part of this study. To guarantee that system functions are in line with user needs as determined by the survey results, the development process employed an organized, user-centered methodology.

The application was designed and built using iterative development techniques, which allow for continuous improvement based on testing and evaluation. The development process included functionality testing, database integration, system development, interface design, and requirement analysis.

Requirements Analysis

User requirements were determined through data analysis and survey results. The results showed the necessary

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features, usability factors, and system priorities to ensure that the application satisfies actual user needs.

System Design

The system was designed to make safe data storage, user interaction, and data processing easier. This means designing user interfaces, defining data flow, and arranging system components to ensure efficacy and scalability.

User Interface Development

The user interface of the application was straightforward and easy to use. Accessibility, navigation flow, and layout structure were all taken into account to encourage user engagement and ease of use.

Figure 1. Log In

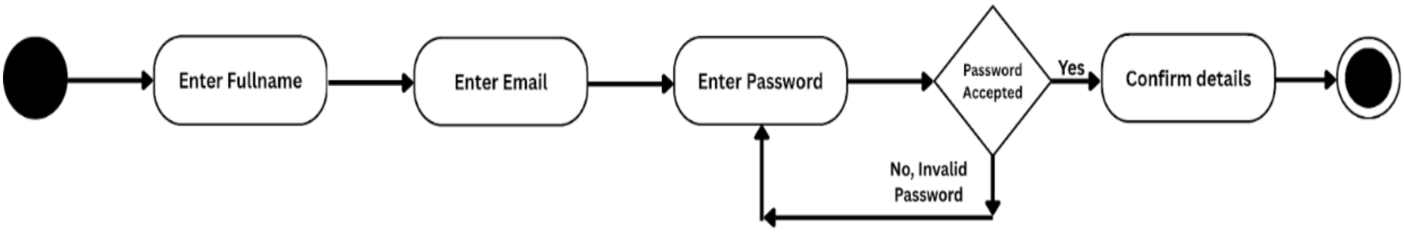

Figure 2. Sign Up

These interfaces demonstrate the layout structure and navigation flow designed to ensure ease of use and accessibility.

Image Processing and Classification Integration

The application utilized Computer Vision for automated waste identification, specifically leveraging the Google Gemini AI model for its pre-trained visual recognition capabilities. To ensure the AI could accurately distinguish between the university's four waste categories such as residual, special, non-biodegradable, and biodegradable, the system was refined through prompt engineering. This involved setting specific logical parameters that allowed the AI to analyze the shape, texture, and material of plastic waste commonly found on campus, thereby providing real-time, accurate disposal instructions (Wang & Pokharel, 2025; Ying, 2025).

Figure 3. Waste Recognition Process

The process flow shows how the system captures input, performs recognition, and generates a system response.

Database Development and Management

Data generated by the system and user input were stored in a centralized database. Appropriate data structuring and security measures were implemented to ensure data integrity, protect user privacy, and support efficient data retrieval.

System Testing and Evaluation

The prototype went through performance evaluation, usability testing, and functionality testing. Testing feedback used to improve the system's dependability and user experience.

Data Collection Procedure

A letter addressed to the Vice President for Administration, validators, students, staff, and statistician sent to get permission to conduct the study. The students and staff asked for informed consent to sign. The questionnaires (instruments) were sent online to collect data.

Statistical Analysis

Mean and standard deviation were used to analyze Likert-scale items, while frequency and percentage were applied to non-Likert questions. Cramer's V was employed to determine the associations among awareness, waste segregation practices, perceptions of the AI-based mobile application, gamification and engagement, sustainability outcomes, and institutional factors, with a significance level of 0.05. All statistical analyses were performed using Minitab statistical software.

Storage of Data Acquired

Data from surveys and observations were securely stored in a cloud-based database and backed up on encrypted external drives to ensure confidentiality and ease of access for analysis.

Limitations of the Study

This study has certain limitations regarding generalizability. The sample is heavily represented by the College of Engineering (86%), which may introduce a response bias as these students may have a higher baseline interest in AI technology. Additionally, the study measures the perceived improvement in waste segregation rather than objective longitudinal data on actual waste weight reduction. Future studies should include a more balanced representation of university colleges and objective waste audits.

RESULTS

The Socio-Demographic Profile of the Students and Staff

Table 1: Socio-Demographic of the Respondents

	Student		Staff	
Group	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Age:				
18-25	188	91	2	5
26-40	16	8	20	51
41 and up	3	1	17	44
Gender:				
Male	104	51	20	51
Female	100	48	18	46
Prefer not to say	3	1	1	3
Role in the University:				
College of Architecture	4	2		
College of Business Administration	2	1		
College of Computing and Information Technology	18	9		
College of Education and Liberal Arts	1	1		

College of Engineering	179	86		
College of Law	1	1		
College of Nursing	0	0		
College of Pharmacy	0	0		
College of Science	2	1		
Staff:				
Co-Academic			29	74
Academic			10	26
Total	207	100	39	100

The largest percentage of the students (f = 188, % = 91) aged 18-25 years old. While the least (f = 3, % = 1) among the 207 respondents. Among the 39 academic and nonacademic staff, 39 responded. Among the staff, the largest group was aging 26-40 (f = 20; %= 51). While the lowest group came from 18-25 years old (f = 2; % = 5).

Most of the respondents were male (f = 104; % = 51), but very close to the female (f = 100; % = 48) while only very few (f = 3; % = 1) did not say the gender. Among the staff, more than half (f = 20; % = 51) were males and very few (f = 1; % = 3) preferred not to say their sex. The largest respondents came from the College of Engineering (f = 179; % = 86) while there were no respondents from the College of Nursing (f = 0; % = 0) and College of Pharmacy (f = 0; % = 0). Among the 39 staff, the co-academic had the respondents (f = 29; % = 74).

Students' and Staff's Level of Awareness in Plastic Waste Management

Table 2: Respondents' Level of Awareness in Plastic Waste Management

Group	**Mean**	**SD**	**Interpretation**
Student:			
Age:			
18-25	3.47	0.80	Familiar
26-40	2.75	0.22	Somewhat Familiar
41 and up	2.92	0.29	Somewhat Familiar
Gender:			
Male	3.49	0.79	Familiar
Female	3.48	0.81	Familiar
Prefer not to say	3.17	1.04	Somewhat Familiar
As a whole	3.21	0.66	Somewhat Familiar
Staff:			
Age:			
18-25	3.88	0.88	Familiar
26-40	4.34	0.42	Very Familiar
41 and up	4.66	0.33	Very Familiar
Gender:			
Male	3.28	0.85	Somewhat Familiar
Female	3.81	0.64	Familiar
Prefer not to say	4.50	0.00	Very Familiar
As a whole	4.04	0.64	Familiar

Scale: 1.00 - 1.79 - Not Familiar; 1.80 - 2.59 - Slightly Familiar; 2.60 - 3.39 - Somewhat Familiar; 3.40 - 4.19 - Familiar; 4.20 - 5.00 - Very Familiar

The students (mean =3.21; sd = .66) were somewhat familiar while the staff (mean =4.04; sd = .64) were familiar with plastic waste segregation.

Students' and Staff's Level of Current Plastic Waste Segregation Practices

Table 3: Respondents' Level of Practices in Plastic Waste Management

Group	Mean	SD	Interpretation
Student:			
Age:			
18-25	3.81	0.67	Often
26-40	3.65	0.95	Often
41 and up	3.56	0.96	Often
Gender:			
Male	3.74	0.73	Often
Female	3.84	0.67	Often
Prefer not to say	3.89	0.70	Often
As a whole	3.75	0.78	Often
Staff:			
Age:			
18-25	2.00	0.95	Never
26-40	3.87	0.81	Often
41 and up	3.71	0.61	Often
Gender:			
Male	3.65	0.87	Often
Female	3.80	0.79	Often
Prefer not to say	3.00	0.00	Sometimes
As a whole	3.34	0.81	Sometimes

Scale: 1.00 - 1.79 - Never; 1.80 - 2.59 - Rarely; 2.60 - 3.39 - Sometimes; 3.40 - 4.19 - Often; 4.20 - 5.00 – Always

The results showed that students often practiced (mean =3.75; sd = .78) and staff (mean =3.34; sd = .81) practiced sometimes in plastic waste segregation.

Perception on the Use of AI and Mobile Application on Plastic Waste Management

Table 4: Perception on the Use of AI and Mobile Application

Group	Mean	SD	Interpretation
Student:			
Age:			
18-25	3.70	0.88	Agree
26-40	3.56	1.27	Agree
41 and up	3.00	0.50	Neutral
Gender:			
Male	3.65	0.95	Agree
Female	3.75	0.85	Agree
Prefer not to say	2.61	1.21	Neutral
As a whole	3.38	0.94	Neutral
Staff:			
Age:			
18-25	1.67	0.23	Strongly Disagree
26-40	3.48	1.10	Agree
41 and up	3.68	0.84	Agree

Gender:			
Male	3.12	1.20	Neutral
Female	3.91	0.70	Agree
Prefer not to say	2.83	0.00	Neutral
As a whole	3.12	0.82	Neutral

Scale: 1.00 - 1.79 - Strongly Disagree; 1.80 - 2.59 - Disagree; 2.60 - 3.39 - Neutral; 3.40 - 4.19 - Agree; 4.20 - 5.00 - Strongly Agree

The students (*mean* =3.38; *sd* = .94) and staff (*mean* =3.12; *sd* = .82) were neutral on their views on the use of AI and Mobile Application on sustainability.

Perceptions on Gamification and Engagement Features

Table 5: Perceptions on Gamification and Engagement

Group	**Mean**	**SD**	**Interpretation**
Student:			
Age:			
18-25	4.03	0.78	Agree
26-40	3.81	1.05	Agree
41 and up	3.67	0.58	Agree
Gender:			
Male	3.94	0.79	Agree
Female	4.11	0.76	Agree
Prefer not to say	2.58	1.23	Disagree
As a whole	3.69	0.87	Agree
Staff:			
Age:			
18-25	2.88	0.53	Neutral
26-40	3.87	0.82	Agree
41 and up	3.99	0.71	Agree
Gender:			
Male	3.56	0.89	Agree
Female	4.21	0.50	Strongly Agree
Prefer not to say	4.00	0.00	Neutral
As a whole	3.75	0.69	Agree

Scale: 1.00 - 1.79 - Strongly Disagree; 1.80 - 2.59 - Disagree; 2.60 - 3.39 - Neutral; 3.40 - 4.19 - Agree; 4.20 - 5.00 - Strongly Agree

The students (mean =3.69; sd = .87) and staff (mean =3.75; sd = .69) agreed that gamification features affect user motivation.

Perceived Sustainability Outcomes for Improved Waste Management Practices

Table 6: Sustainability Outcomes for Improved Waste Management

Group	**Mean**	**SD**	**Interpretation**
Student:			
Age:			

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18-25	4.26	0.65	Strongly Agree
26-40	4.28	0.86	Strongly Agree
41 and up	4.83	0.29	Strongly Agree
Gender:			
Male	4.19	0.73	Agree
Female	4.35	0.60	Strongly Agree
Prefer not to say	4.17	0.29	Agree
As a whole	4.35	0.57	Strongly Agree
Staff:			
Age:			
18-25	2.75	1.06	Neutral
26-40	4.30	0.71	Strongly Agree
41 and up	4.50	0.56	Strongly Agree
Gender:			
Male	4.17	0.86	Agree
Female	4.42	0.60	Strongly Agree
Prefer not to say	5.00	0.00	Strongly Agree
As a whole	4.19	0.76	Agree

Scale: 1.00 - 1.79 - Strongly Disagree; 1.80 - 2.59 - Disagree; 2.60 - 3.39 - Neutral; 3.40 - 4.19 - Agree; 4.20 - 5.00 - Strongly Agree

Students (mean =4.35; sd =.57) strongly agree while the staff (mean =4.19; sd = .76) regarding the contribution of waste management and AI applications to sustainability.

Institutional Effectiveness on Plastic Waste Management

Table 7: Institutional Effectiveness on Plastic Waste Management

Group	**Mean**	**SD**	**Interpretation**
Student:			
Age:			
18-25	3.84	0.77	Agree
26-40	3.83	1.04	Agree
41 and up	3.11	1.02	Neutral
Gender:			
Male	3.76	0.81	Agree
Female	3.91	0.79	Agree
Prefer not to say	3.45	0.69	Agree
As a whole	3.65	0.85	Agree
Staff:			
Age:			
18-25	1.34	0.47	Strongly Disagree
26-40	3.88	0.82	Agree
41 and up	3.80	0.73	Agree
Gender:			
Male	3.54	1.19	Agree
Female	3.89	0.57	Agree
Prefer not to say	4.00	0.00	Agree
As a whole	3.41	0.76	Agree

Scale: 1.00 - 1.79 - Strongly Disagree; 1.80 - 2.59 - Disagree; 2.60 - 3.39 - Neutral; 3.40 - 4.19 - Agree; 4.20 - 5.00 - Strongly Agree

The students (mean =3.65; sd = .85) and staff (mean =3.41; sd = .76) agree to institutional effectiveness on plastic waste management.

Association among the Different Variables

Table 8: Association among the Different Variables

Variable	Cramer's V	p-value	Interpretation
Awareness and Practices	0.34	<.001	Significant
Awareness and Perception	0.2	0.003	Significant
Awareness and Gamification	0.15	0.139	Not Significant
Awareness and Institutional Effectiveness	0.205	<.001	Significant
Practices and Perception	0.22	<.001	Significant
Practices and Gamification	0.259	<.001	Significant
Practices and Sustainability	0.25	<.001	Significant
Practices and Institutional Effectiveness	0.321	<.001	Significant
Perception and Gamification	0.29	<.001	Significant
Perception and Sustainability	0.375	<.001	Significant
Perception and Institutional Effectiveness	0.247	<.001	Significant
Gamification and Sustainability	0.336	<.001	Significant
Gamification and Institutional Effectiveness	0.365	<.001	Significant
Sustainability and Institutional Effectiveness	0.377	<.001	Significant

p-value: 0.05

A significant association was found between all variable pairs except Awareness and Gamification.

Waste Collection and Institutional Management Perspective Among Janitorial Staff, MRF Operators, Sustainability Officers, and other Personnel Involved in Waste Collection.

Table 9: Waste Collection and Institutional Management Perspective

Item	Frequency	Percentage (%)
Approximate Plastic Waste Collected per Week:		
Less than 10kg	5	17.90
10kg-30kg	9	32.10
31kg-50kg	5	17.90
More than 50kg	9	32.10
Total	28	100
Current Waste Classification and Segregation at the MRF:		
Manual Sorting Type	13	46.40
Mixed Waste (Sorted Later)	8	28.60
QR/Label-based Sorting	7	25.00
Total	28	100
Monitoring or Reporting Waste Collection Data:		
Daily	17	60.71
Weekly	7	25.01
Monthly	2	7.14
Never	2	7.14
Total	28	100

The approximate amount of plastic waste collected every week, the highest responses were “10-30kg” and “More than 50kg”, both with 32.10% (f = 9). Meanwhile, “31-50kg” and “Less than 10kg” both had 17.90% (f=5).

In terms of waste classification and segregation at the Material Recovery Facility (MRF), most staff said that manual sorting type is commonly used with 46.40% (f = 13). Mixed waste sorted later followed with 28.60% (f = 8), while QR/label-based sorting had 25.00% (f =7).

For monitoring or reporting waste collection data, most staff answered daily monitoring with 60.71% (f = 17). Weekly monitoring followed with 25.01% (f = 7). Only a few respondents answered monthly (7.14%, f =2) and never (7.14%, f = 2).

Factors Affecting Proper Plastic Waste Segregation on Campus

Table 10: Factors of Affecting Proper Plastic Waste Segregation on Campus

Factors	Mean	SD	Interpretation
Lack of cooperation from students and staff	3.71	1.08	Agree
Insufficient bins or labels	3.14	1.33	Neutral
Inconsistent collection schedule	3.26	1.32	Neutral
Lack of training/manpower	3.50	1.37	Agree

Scale: 1.00 - 1.79 - Strongly Disagree; 1.80 - 2.59 - Disagree; 2.60 - 3.39 - Neutral; 3.40 - 4.19 - Agree; 4.20 - 5.00 - Strongly Agree

The respondents (*mean* =3.40; *sd* = 1.28) agreed that several factors affect proper plastic waste segregation on campus, particularly the lack of cooperation, training, and manpower within the institution.

Effectiveness of an AI-Powered Mobile Application in Improving the Current System on Plastic Waste Management

Table 11: AI-Powered Mobile Application Effectiveness

Factors	Mean	SD	Interpretation
Would an AI-powered mobile application (with real-time tracking and waste classification) help improve the current system?	3.71	1.08	Agree

The staff agreed (mean =3.71; sd = 1.08) on the effectiveness of an AI-Powered Mobile Application in improving the current system on plastic waste management.

The Existing Campaign Strategies and Institutional Efforts are Implemented to Promote Waste Segregation and Sustainability in the Campus

Table 12: Existing Campaign Strategies and Efforts of the Institution

Campaign Strategies	Frequency	Percentage (%)
Integration in classroom activities	3	10.70
Posters/signages	8	28.60
Seminars/workshops	10	35.70

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Social media campaigns	7	25.00
Total	28	100

Regarding how the university communicates waste management initiatives, seminars, and workshops got the highest percentage with 35.70% (f =10). Poster and signages followed with 28.60% (f = 8), while social media campaigns had 25.00% (f = 7). Integration in classroom activities had the lowest percentage with 10.70% (f = 3).

Evaluation of the Developed Mobile Application using AI in Terms of Usability

Table 13: Evaluation of the Developed Mobile Application using AI of Usability

Indicators	Mean	SD	Interpretation
What usability features did you find important when using the app?:			
Easy-to-navigate interface	4.53	0.81	Strongly Agree
Clear and simple instructions for scanning waste	4.58	0.69	Strongly Agree
Visually appealing and user-friendly design	4.64	0.76	Strongly Agree
As a whole	4.58	0.75	Strongly Agree

Scale: 1.00 - 1.79 - Strongly Disagree; 1.80 - 2.59 - Disagree; 2.60 - 3.39 - Neutral; 3.40 - 4.19 - Agree; 4.20 - 5.00 - Strongly Agree

As a whole, the students and staff (mean =4.58; sd = 0.75) strongly agreed with the most statements regarding application usability.

Evaluation of Mobile Application Using Artificial Intelligence in Terms of Importance of Features on Plastic Waste Identification

Table 14: Evaluation of the Developed Mobile Application using AI in terms of Importance of Plastic Waste Identification

Indicators	Mean	SD	Interpretation
Which plastic waste identification features of the app are important?:			
Identification of biodegradable and non-biodegradable plastic waste	4.50	0.85	Very Important
Identification of special or hazardous plastic waste	4.64	0.80	Very Important
Identification of residual plastic waste	4.53	0.70	Very Important
Clear and accurate disposal instructions after scanning	4.56	0.81	Very Important
As a whole	4.56	0.79	Very Important

Scale: 1.00 - 1.79 - Not Important; 1.80 - 2.59 - Slightly Important; 2.60 - 3.39 - Moderately Important; 3.40 - 4.19 - Important; 4.20 - 5.00 - Very Important

All features on the plastic waste segregation were very important (mean =4.56; sd = 0.79).

Evaluation of Mobile Application Using Artificial Intelligence in Terms of Importance of Features on Gamification Elements

Table 15: Evaluation of the Developed Mobile Application using AI in terms of Importance on Gamification Elements

Indicators	Mean	SD	Interpretation
Which gamification features of the app are important for motivating proper waste disposal?:			
Points or rewards for proper waste disposal	4.50	0.61	Very Important
Badges, levels, or achievements	4.36	0.644	Very Important
Challenges or missions related to waste management	4.42	0.65	Very Important
As a whole	4.43	0.63	Very Important

Scale: 1.00 - 1.79 - Not Important; 1.80 - 2.59 - Slightly Important; 2.60 - 3.39 - Moderately Important; 3.40 - 4.19 - Important; 4.20 - 5.00 - Very Important

Gamification (mean =4.43; sd = .63) of mobile application using artificial intelligence can identify the kinds of plastic waste, gamification elements are highly valuable and essential.

Evaluation of Mobile Application Using Artificial Intelligence in Terms of Importance of Features on Engagement and Behavior Support

Table 16: Evaluation of the Developed Mobile Application using AI in terms of Importance of Features on Engagement and Behavior Support

Indicators	Mean	SD	Interpretation
Which features of the app encourage proper waste disposal behavior?			
Features that motivate proper waste segregation	4.56	0.69	Very Important
Feedback on waste disposal performance	4.47	0.77	Very Important
Reminders or prompts for proper waste disposal	4.50	0.77	Very Important
As a whole	4.51	0.74	Very Important

Scale: 1.00 - 1.79 - Not Important; 1.80 - 2.59 - Slightly Important; 2.60 - 3.39 - Moderately Important; 3.40 - 4.19 - Important; 4.20 - 5.00 - Very Important

According to them, all features on engagement and behavior support were considered very important (mean =4.51; sd = 0.74).

Evaluation of Mobile Application Using Artificial Intelligence in Terms of Features on Environmental Awareness

Table 17: Evaluation of the Developed Mobile Application using AI in terms of Features on Environmental Awareness

Indicators	Mean	SD	Interpretation
Which environmental awareness features did the app provide effectively?			
Information about different waste categories	4.50	0.65	Strongly Agree
Environmental impact of improper waste disposal	4.58	0.60	Strongly Agree
Information on the university’s sustainability efforts	4.33	0.79	Strongly Agree
As a whole	4.47	0.68	Strongly Agree

Scale: 1.00 - 1.79 - Strongly Disagree; 1.80 - 2.59 - Disagree; 2.60 - 3.39 - Neutral; 3.40 - 4.19 -Agree; 4.20 - 5.00 - Strongly Agree

The students also strongly agreed that the mobile application using AI promoted environmental awareness (mean =4.47; sd = 0.68).

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Evaluation of Mobile Application Using Artificial Intelligence in Terms of Features on Technical Performance

Table 18: Evaluation of the Developed Mobile Application using AI on Technical Performance Features

Indicators	Mean	SD	Interpretation
Which technical performance features of the app worked well?			
Fast response time after scanning	4.08	0.94	Agree
Reliable scanning in different lighting conditions	4.31	0.82	Strongly Agree
How would you rate the performance of the mobile application?	4.31	0.75	Excellent Performance
As a whole	4.23	0.84	Strongly Agree/Excellent Performance

Scale: 1.00 - 1.79 - Strongly Disagree/Very Poor Performance; 1.80 - 2.59 - Disagree/Poor Performance; 2.60 - 3.39 - Neutral; 3.40 - 4.19 -Agree/Good Performance; 4.20 - 5.00 - Strongly Agree/Excellent Performance

The students strongly agreed with the features related to technical performance and rated the developed AI-powered mobile application as having excellent performance (mean =4.23; sd = 0.84).

Evaluation of Mobile Application Using Artificial Intelligence in Terms of Determinants of Application

Table 19: Evaluation of the Developed Mobile Application using AI in terms of Determinants of Application

Indicators	Mean	SD	Interpretation
After using the AI-enabled mobile application, my consistency in properly segregating plastic waste on campus improved.	4.36	0.68	Strongly Agree
Based on experience using the AI-enabled mobile application, it improves the accuracy of plastic waste segregation.	4.50	0.65	Strongly Agree
The gamification features in the mobile application motivated me to practice proper waste segregation.	4.53	0.65	Strongly Agree
Using the AI-enabled mobile application contributes to reducing environmental impact through improved waste segregation.	4.47	0.65	Strongly Agree
The AI-enabled mobile application improves the effectiveness of waste management operations.	4.58	0.60	Strongly Agree
The mobile application enhances the effectiveness of university sustainability campaigns.	4.44	0.61	Strongly Agree
The AI-enabled mobile application improved my plastic waste segregation behavior.	4.50	0.61	Strongly Agree
As a whole	4.48	0.64	Strongly Agree

Scale: 1.00 - 1.79 - Strongly Disagree; 1.80 - 2.59 - Disagree; 2.60 - 3.39 - Neutral; 3.40 - 4.19 -Agree; 4.20 - 5.00 - Strongly Agree

The respondents strongly agreed on the determinants of using the mobile application with AI (mean =4.48; sd = 0.64).

Evaluation of Mobile Application Using Artificial Intelligence in Terms of Overall Satisfaction

Table 20: Evaluation of the Developed Mobile Application using AI in terms of Overall Satisfaction

Indicators	Mean	SD	Interpretation
The mobile application's overall features:	4.44	0.69	Strongly Agree
Provide an enjoyable and engaging app experience	4.39	0.84	Strongly Agree
Make me willing to recommend the app to others	4.36	0.76	Strongly Agree
As a whole	4.40	0.76	Strongly Agree

Scale: 1.00 - 1.79 - Strongly Disagree; 1.80 - 2.59 - Disagree; 2.60 - 3.39 - Neutral; 3.40 - 4.19 -Agree; 4.20 - 5.00 - Strongly Agree

The respondent strongly agreed that they were satisfied with using the application (mean =4.40; sd = 0.76).

DISCUSSION

Socio-Demographic Profile of Respondents

The study involved 207 student respondents and 39 academic and non-academic staff from Adamson University. Among students, the majority (91%, f = 188) belonged to the 18–25 age group, were predominantly male (51%, f = 104), with females closely following (48%, f = 100). The largest proportion of student respondents came from the College of Engineering (86%, f = 179), reflecting heightened interest in the AI-powered mobile application given its engineering orientation. Among staff, the dominant age group was 26–40 (51%, f = 20), with males comprising the majority (51%, f = 20), and co-academic staff representing 74% (f = 29) of the staff respondents.

Level of Awareness on Plastic Waste Segregation

Students as a whole were found to be somewhat familiar with plastic waste segregation (mean = 3.21; SD = .66), while staff demonstrated a higher level of familiarity (mean = 4.04; SD = .64). Among student subgroups, those aged 18–25 were familiar (mean = 3.47; SD = .80), while those aged 26–40 and 41 and above were only somewhat familiar (means of 2.75 and 2.92, respectively). Among staff, older age groups showed higher awareness, with those aged 26–40 rating as very familiar (mean = 4.34) and those 41 and above rating even higher (mean = 4.66).

The moderate awareness among students suggests that while they possess a general understanding of plastic waste management, gaps remain in their knowledge of specific practices and policies. This is consistent with the findings of Molina et al. (2021), who reported that students demonstrate sufficient awareness of the definition of solid waste and the consequences of improper disposal, yet often fall short in knowing institutional rules and their own responsibilities in waste management. Staff's higher awareness levels may be attributed to their longer institutional experience and direct involvement in waste management operations.

Level of Practices on Plastic Waste Segregation

Students often practiced plastic waste segregation (mean = 3.75; SD = .78), while staff practiced it only sometimes (mean = 3.34; SD = .81). Across student subgroups, all age groups and genders consistently reported often practicing segregation, reflecting a relatively active behavioral engagement. Among staff, however, those aged 18–25 reported never practicing segregation (mean = 2.00), whereas older staff groups (26–40 and 41 and above) reported practicing it often.

The finding that students practice segregation more frequently than staff is notable and may reflect the greater exposure of students to campus sustainability campaigns and peer influence. These results contrast with the findings of Apevienyeku et al. (2025), who reported that respondents in their study always practiced segregation of plastic wastes, suggesting that practice levels may vary considerably depending on institutional context, enforcement mechanisms, and the type of waste being managed.

Perception on AI-Based Mobile Application on Plastic Waste Management

Both students (mean = 3.38; SD = .94) and staff (mean = 3.12; SD = .82) were *neutral* in their overall perceptions regarding the use of AI and mobile applications for plastic waste management. However, notable differences emerged across subgroups. Among students, those aged 18–25 and those in the 26–40 age group expressed agreement (means of 3.70 and 3.56, respectively), while older students and those who preferred not to disclose their gender were neutral. Among staff, females agreed (mean = 3.91), while males and those who preferred not to disclose were neutral.

The neutral stance of the overall sample may reflect a general unfamiliarity or cautious disposition toward technology-driven waste management solutions, rather than outright resistance. This stands in contrast to the findings of Faisal et al. (2018), who reported that educational institutions actively utilizing cloud-based systems for waste monitoring experienced enhanced collection rates and increased recycling awareness. The gap between current practice and the potential of AI-based systems underscores the need for targeted technology awareness programs and demonstration initiatives within the university.

Perceptions on Gamification and Engagement Features

Both students (mean = 3.69; SD = .87) and staff (mean = 3.75; SD = .69) agreed that gamification and engagement features affect user motivation in waste management activities. Female students strongly agreed (mean = 4.11), while students who preferred not to disclose their gender strongly disagreed (mean = 2.58), representing an outlier in the generally positive pattern. Among staff, female respondents strongly agreed (mean = 4.21), further reinforcing gender-based differences in receptiveness to gamified features.

The agreement on gamification's role in motivating user behavior aligns with the broader literature on this topic. Weitzel et al. (2025) demonstrated that gamified mobile applications, through mechanisms such as leaderboards, peer competition, and continuous digital feedback, significantly outperformed non-gamified approaches in sustaining long-term recycling participation. Similarly, Aguiar-Castillo et al. (2018) found that perceived utility, social benefits, and risk considerations were key determinants of user intention to engage with gamified sustainability applications, consistent with the Technology Acceptance Model (TAM). These findings validate the integration of gamification features — including point systems, leaderboards, and QR code-based validation — in the developed application.

Perceived Sustainability Outcomes of Improved Waste Management Practices

Students strongly agreed (mean = 4.35; SD = .57) that improved plastic waste management, supported by AI applications, contributes to sustainability outcomes. Staff, while slightly lower, still agreed overall (mean = 4.19; SD = .76). Notably, older students (41 and above) expressed the strongest agreement (mean = 4.83), and female staff strongly agreed (mean = 4.42), reflecting a general cross-demographic belief in the environmental value of improved waste management.

These results affirm the perceived importance of integrating AI technology into waste management systems for sustainability. Abdallah et al. (2020) support this finding, demonstrating that AI-based image recognition systems can reduce the need for manual waste sorting and enable predictive modeling of waste generation, thereby lowering operational costs and improving environmental sustainability outcomes. The strong endorsement by respondents suggests an existing readiness to embrace AI-driven solutions, provided appropriate institutional support and accessible platforms are made available.

Institutional Effectiveness on Plastic Waste Management

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Both students (mean = 3.65; SD = .85) and staff (mean = 3.41; SD = .76) agreed that the institution's current waste management operations support proper plastic waste segregation and that technological assistance is needed to improve segregation behavior. However, younger staff (aged 18–25) showed strong disagreement (mean = 1.34), which may reflect the limited involvement of entry-level personnel in institutional waste management decisions.

The general agreement on institutional effectiveness indicates a baseline level of confidence in the university's waste management systems. However, the variability across subgroups suggests that perceptions of institutional support are uneven and may depend on one's direct involvement in or exposure to waste management operations. These findings reinforce the importance of inclusive institutional communication strategies that engage all campus stakeholders.

Association among the Different Variables

Cramer's V analysis revealed significant associations among nearly all variable pairs ($p < 0.05$), with the sole exception of Awareness and Gamification (V = 0.15; p = 0.139). The strongest association was between Sustainability and Institutional Effectiveness (V = 0.377), followed by Perception and Sustainability (V = 0.375) Gamification and Institutional Effectiveness (V = 0.365), Gamification and Sustainability (V = 0.336), Perception and Gamification (V = 0.29), and Perception and Institutional Effectiveness (V = 0.247).

The strong Perception–Institutional Effectiveness link suggests that how respondents view AI and mobile applications directly relates to their evaluation of the university's anti-plastic waste efforts — consistent with Lunar et al. (2025), who found that sustainability initiatives drive institutional effectiveness and that institutions pursuing such programs are viewed more favorably.

Significant associations involving Practices — with Sustainability (V = 0.25) and Institutional Effectiveness (V = 0.321) — confirm that actual waste segregation behavior shapes both environmental and institutional perceptions. Holst et al. (2024) support this, noting that whole-institution sustainability approaches empower learners and educators alike, creating an enabling environment for responsible behavior.

The significant Awareness–Practices association (V = 0.34) indicates that greater awareness correlates with more frequent practice. Yet the non-significant Awareness–Gamification result implies awareness alone does not drive gamified engagement — consistent with Abeysekera et al. (2022), who found that environmental awareness plays only a limited, mediated role in behavioral change and requires additional motivational strategies for sustained action.

Finally, Gamification's strong associations affirm its bridging role between engagement and sustainability. Shahzad et al. (2023) found gamification positively influences green consumption behavior through technological awareness, motivation, and enjoyment — aligning with this study's finding that gamification is meaningfully linked to both sustainability outcomes and institutional effectiveness.

Waste Collection and Institutional Management Perspective

Among the 28 janitorial staff, MRF operators, sustainability officers, and related personnel surveyed, the highest frequencies for weekly plastic waste collection were tied between "10–30 kg" and "more than 50 kg" (32.10% each), indicating variability across campus collection points. Manual sorting was the predominant method of waste classification at the MRF (46.40%), followed by mixed waste sorted later (28.60%) and QR/label-based sorting (25.00%). The majority of staff reported daily monitoring of waste collection data (60.71%), reflecting an active operational engagement.

The high prevalence of manual sorting suggests the campus has not yet adopted technology-driven classification systems, a gap that the developed AI-powered application seeks to address. The per-campus waste volume was comparatively lower than the figures reported by Casarejos et al. (2017), who noted that private higher education institutions in the United States generate an average of 1.81 kg per student per day. This discrepancy may be attributed to differences in institutional scale, waste generation culture, and campus food and consumption patterns.

Regarding institutional factors affecting waste segregation, staff identified lack of cooperation from students and fellow staff (mean = 3.71; SD = 1.08) and lack of training and manpower (mean = 3.50; SD = 1.37) as agreed-upon barriers. Insufficient bins or labels (mean = 3.14) and inconsistent collection schedules (mean = 3.26) were rated as neutral factors. Uehara et al. (2022) offer a practical approach to the cooperation challenge, noting that clearly designated waste rules constitute a simple yet effective strategy for improving waste separation behavior in institutional contexts.

Factors Affecting Proper Plastic Waste Segregation on Campus

Respondents agreed (mean = 3.40; SD = 1.28) that several factors hinder proper plastic waste segregation on campus. Lack of cooperation from students and staff (mean = 3.71) and lack of training and manpower (mean = 3.50) were identified as the most significant barriers, while insufficient bins or labels (mean = 3.14) and inconsistent collection schedules (mean = 3.26) were viewed as neutral concerns.

These findings highlight those behavioral and organizational factors — rather than infrastructure gaps alone — are primary obstacles to effective waste segregation. The perceived need for cooperation and training supports the proposition that an AI-powered mobile application with interactive and educational features can serve as a practical intervention. Sidhu et al. (2021) demonstrated that combining smart technologies with mobile applications for waste management can optimize collection efficiency and reduce unnecessary trips, addressing both operational and behavioral dimensions of waste management.

Effectiveness of an AI-Powered Mobile Application in Improving the Current Waste Management System

Staff agreed (mean = 3.71; SD = 1.08) that an AI-powered mobile application with real-time tracking and waste classification capabilities would improve the campus waste management system. This receptiveness among operational personnel is significant, as their cooperation is essential to the successful implementation of any technology-based waste management solution. The study of Sidhu et al. (2021) corroborates this view, demonstrating that AI-integrated mobile platforms can improve the efficiency of waste collection systems by enabling real-time data gathering and route optimization.

Existing Campaign Strategies and Institutional Efforts

The primary communication channels used by the university to promote waste management initiatives were seminars and workshops (35.70%, f = 10), followed by posters and signages (28.60%, f = 8), social media campaigns (25.00%, f = 7), and integration in classroom activities (10.70%, f = 3). The dominance of passive and event-driven communication methods over continuous, curriculum-integrated strategies suggests an opportunity for deeper embedding of waste management education into academic activities. Uehara et al. (2022) support this direction, finding that the clear designation of waste management rules in institutional settings promotes more consistent segregation behavior among students and staff.

Evaluation of the Developed AI-Powered Mobile Application in Terms of Usability

Respondents strongly agreed (mean = 4.58; SD = 0.75) that the application was easy to navigate, provided clear and simple scanning instructions (mean = 4.58; SD = .69), and featured a visually appealing and user-friendly design (mean = 4.64; SD = .76). These ratings are consistent with Ali et al. (2022), who identified effectiveness, efficiency, and satisfaction as key usability attributes determining mobile application acceptance. Sun et al. (2024) similarly found that AI-integrated waste management platforms received positive usability ratings from student users, while Weichbroth (2024) confirmed that usability is directly linked to user satisfaction in mobile applications.

Evaluation of the Developed AI-Powered Mobile Application in Terms of Importance of Features on Plastic Waste Identification

All plastic waste identification features were rated as *very important* (mean = 4.56; SD = .79). Specific features — including identification of biodegradable and non-biodegradable waste (mean = 4.50), hazardous plastic waste (mean = 4.64), residual plastic waste (mean = 4.53), and clear disposal instructions after scanning (mean = 4.56) — received consistently high ratings. Ramos et al. (2024) support these findings, noting that AI-based plastic waste classification systems frequently achieve accuracy rates exceeding 80%, while Wang and Pokharel (2025) validated a comparable system achieving over 95% accuracy using the YOLO algorithm, demonstrating the reliability of AI-powered waste identification in mobile platforms.

Evaluation of the Developed AI-Powered Mobile Application in Terms of Importance of Gamification Elements

Gamification features were collectively rated as *very important* (mean = 4.43; SD = .63). Points or rewards for proper waste disposal (mean = 4.50), badges and achievements (mean = 4.36), and challenges or missions related to waste management (mean = 4.42) were all highly valued. Tundjungsari et al. (2025) demonstrated that gamification mechanics embedded in mobile waste management applications effectively increase user motivation and participation, while Lim et al. (2025) confirmed that user satisfaction derived from gamification shapes perceived contribution to sustainability goals — findings that align closely with the present evaluation results.

Evaluation of the Developed AI-Powered Mobile Application in Terms of Engagement and Behavior Support

Engagement and behavior support features were rated as *very important* overall (mean = 4.51; SD = 0.74), with motivational features (mean = 4.56), performance feedback (mean = 4.47), and disposal reminders (mean = 4.50) all receiving strong endorsement. Santos et al. (2025) support these findings in their systematic review, which found that mobile applications with interactive features sustain behavioral change more effectively than passive information tools. Sun et al. (2024) further confirmed that AI-integrated platforms measurably improved users' sustainability awareness and practical waste sorting skills.

Evaluation of the Developed AI-Powered Mobile Application in Terms of Features on Environmental Awareness

Respondents strongly agreed (mean = 4.47; SD = .68) that the application effectively promoted environmental awareness. Features providing information on waste categories (mean = 4.50), environmental impacts of improper waste disposal (mean = 4.58), and the university's sustainability efforts (mean = 4.33) were all rated positively. These results reinforce the value of embedding educational content within functional waste management tools, ensuring that users not only segregate waste correctly but also understand the broader environmental significance of their actions.

Evaluation of the Developed AI-Powered Mobile Application in Terms of Technical Performance

The application received strong technical performance ratings overall (mean = 4.23; SD = .84), with reliable scanning under different lighting conditions (mean = 4.31) rated higher than response time after scanning (mean = 4.08). Overall performance was assessed as *excellent*. These results are consistent with Gao et al. (2025), who reported that 80% of college students found an AI-powered gamification mobile system reliable and positively evaluated its real-time action recognition capabilities.

Evaluation of the Developed AI-Powered Mobile Application in Terms of Determinants of Application Use

Respondents strongly agreed (mean = 4.48; SD = .64) across all determinants of AI application use. They reported improvements in consistency of proper plastic waste segregation (mean = 4.36), accuracy of segregation (mean = 4.50), and overall waste management effectiveness (mean = 4.58) after using the application. The gamification features were credited with motivating proper segregation practices (mean = 4.53), while the application was also seen as contributing to reducing environmental impact (mean = 4.47) and enhancing the effectiveness of university sustainability campaigns (mean = 4.44). These outcomes are supported by Sun et al. (2024), who found measurable improvements in waste sorting skills following the use of an AI educational waste platform, and by Ying (2025), who reported that AI-enabled classification systems raised participation rates from 18% to 63%.

Evaluation of the Developed AI-Powered Mobile Application in Terms of Overall Satisfaction

Respondents strongly agreed (mean = 4.40; SD = .76) with the overall features of the application. Specifically, they found the app enjoyable and engaging (mean = 4.44), expressed willingness to recommend it to others (mean = 4.39), and confirmed that it effectively helped them practice proper waste disposal (mean = 4.36). These satisfaction ratings align with Doğan-Südaş et al. (2023), who found that satisfaction with gamified mobile applications significantly influenced users' willingness to recommend them — a behavioral indicator parallel to the findings of the present study. Gao et al. (2025) further confirmed that 80% of college students were motivated by gamification elements in an AI-powered mobile application, reinforcing the value of combining AI and gamification to produce an enjoyable, sustainability-promoting user experience.

Despite the predominantly positive evaluation, respondents identified areas for further improvement. These included the speed and accuracy of AI-based scanning, broader waste category coverage, enhanced user interface design, improved campus internet connectivity to support application performance, and the incorporation of accessibility features such as voice-activated assistance for persons with disabilities. These suggestions reflect a user-centered perspective that values both functional excellence and inclusive design, and should guide future iterations of the application.

CONCLUSION

The study described the status of plastic waste management at Adamson University and evaluated an AI-powered mobile application with gamification features developed as an institutional response to the identified gaps.

The majority of student respondents were 18–25 years old, male, and from the College of Engineering, while most staff respondents were aged 26–40 and belonged to the co-academic group. Students were found to be somewhat familiar with plastic waste segregation, while staff demonstrated a higher level of familiarity. In terms of practice, students often engaged in proper waste segregation while staff only did so sometimes, indicating a behavioral gap that requires institutional attention.

Both students and staff were neutral in their perceptions of AI and mobile applications for plastic waste management, suggesting that while resistance was not evident, awareness and confidence in technology-driven solutions remain limited. In contrast, both groups agreed that gamification and engagement features positively affect user motivation, and students strongly agreed while staff agreed that improved waste management practices supported by AI contribute to meaningful sustainability outcomes. Both groups likewise agreed on the institutional effectiveness of current waste management operations, though perceptions varied across age groups and roles.

Cramer's V analysis revealed significant associations among nearly all variable pairs, with the strongest link found between Perception and Institutional Effectiveness, followed by Sustainability and Institutional Effectiveness, and Gamification and both Sustainability and Institutional Effectiveness. The only non-significant pair was Awareness and Gamification, indicating that awareness alone is insufficient to drive engagement with gamified features and must be supported by stronger institutional and motivational strategies.

From the perspective of waste collection personnel, manual sorting remained the dominant classification method at the Material Recovery Facility, with daily monitoring as the most common reporting practice. The primary

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barriers to proper plastic waste segregation were identified as lack of cooperation from students and staff, and insufficient training and manpower. The university's existing campaign strategies relied predominantly on seminars, workshops, and visual materials, with limited integration of waste management education into classroom activities.

The developed AI-powered mobile application received strongly positive evaluations across all dimensions. Respondents strongly agreed on its usability, rating the interface as easy to navigate, visually appealing, and clearly instructive. All plastic waste identification features were rated as very important, particularly the identification of hazardous and residual waste and the provision of accurate disposal instructions. Gamification elements including points, badges, and waste-related challenges were similarly rated as very important in motivating proper disposal behavior. Features on engagement and behavior support, environmental awareness, and technical performance all received strong endorsement, with overall performance rated as excellent. Respondents strongly agreed that the application improved their consistency and accuracy in waste segregation, enhanced their environmental awareness, and contributed to the effectiveness of university sustainability efforts. Overall satisfaction was high, with respondents expressing willingness to recommend the application to others.

In sum, the findings affirm that an AI-powered mobile application with gamification features is a viable and effective tool for improving plastic waste management in a university setting. However, its long-term success will depend on sustained institutional support, targeted awareness campaigns, adequate training, and continuous improvements in AI accuracy, waste category coverage, and application accessibility.

RECOMMENDATIONS

Based on the results and findings of the study, the following recommendations are offered:

Strengthen waste segregation policies and infrastructure

The university should institutionalize clearer waste segregation policies, increase the number of properly labeled waste bins across campus, and establish consistent waste collection schedules to support proper plastic waste disposal practices among students and staff.

Upgrade the Material Recovery Facility

The university should consider transitioning from manual sorting to technology-assisted waste classification systems at the MRF to improve sorting efficiency, reduce contamination in recycling streams, and better manage the volume of plastic waste generated on campus.

Integrate waste management education into academic activities

Awareness campaigns should go beyond seminars and visual materials. Waste management topics should be embedded into classroom curricula and co-curricular activities to ensure broader, more sustained engagement among students and staff.

Provide targeted training for staff

Regular training programs on proper plastic waste segregation should be conducted for all staff, particularly those in entry-level and co-academic roles, to bridge the gap between awareness and actual waste management behavior.

Continuously improve the AI-powered mobile application

Future development of the application should focus on enhancing scanning speed and accuracy, expanding waste category coverage, improving accessibility features such as voice-activated assistance for persons with disabilities, and ensuring reliable performance across all campus areas.

Conduct further research on the application's long-term impact

Future researchers are encouraged to expand the scope to other waste categories, conduct longitudinal studies on the sustained behavioral effects of the application, and explore its replicability in other higher education institutions and community settings.

Implementation of Objective Metrics

Future iterations of this research should move beyond descriptive perception surveys and include objective performance indicators. This include conducting “Waste Audits” to measure actual reductions in contamination rates and calculating the recycling efficiency percentage (the ratio of correctly sorted plastic vs. incorrectly sorted plastic) before and after the application is fully deployed in campus.

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Ethical Considerations

The study followed ethical guidelines by obtaining ethics clearance to protect the participant's right and privacy. All respondents agreed to the informed consent before data collection, and their participation was voluntary. Personal information was anonymized, and all data remained confidential.