ISSN: 2149-214X

Journal of Education in Science, Environment and Health

www.jeseh.net

Reducing Environmental Pollution through Behavioral Change and Education: A Repeated Cross-Sectional Pilot Study

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To cite this article:

Shrestha, J., Karki, R., & Adewusi, E. A. (2025). Reducing environmental pollution through behavioral change and education: A repeated cross-sectional pilot study. *Journal of Education in Science, Environment and Health (JESEH), 11*(1), 1-12. https://doi.org/10.55549/jeseh.750

Journal of Education in Science, Environment and Health
Volume 11, Issue 1, 2025 https://doi.org/10.55549/jeseh.750

Reducing Environmental Pollution through Behavioral Change and Education: A Repeated Cross-Sectional Pilot Study

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Article Info

Article History

Published:
01 January 2025

Received:
20 August 2024

Accepted:
24 December 2024

Keywords

Environmental education
Intervention
Waste reduction
Statistical analysis

Abstract

This repeated cross-sectional pilot study examined the impact of environmental education on reducing overall waste generation among students enrolled in an environmental health course from Fall 2020 to Spring 2023. The data included trash generation, single-use plastic, and paper products. Each student logged their daily usage of these waste products in a standard spreadsheet. The data collection phases were divided into three behavioral change intervention timelines: Before-Intervention (BI-Week 1-5), Phase -1 (PH1I- Week 6-10), and Phase-2 Intervention (PH2I-Week 11-14). The study found a significant reduction in the use of grocery bags ($p<0.001$*), produce bags ($p=0.03$*), cutlery/straws ($p=0.01$*), paper towels ($p<0.001$*), toilet paper ($p<0.001$*), the weight ($p=0.003$*) and number($p=0.02$*) of trash. The results indicated that the mean differences in waste such as paper towels $p<0.001$*(PH1I VS BI);$p<0.001$*(PH2I VS BI); $p=0.009$*(PH2I VS PH1I)], toilet paper [$p=0.003$*(PH1I VS BI); $p=0.001$*(PH2I VS BI); $p<0.001$*(PH2I VS PH1I)], grocery bags [$p=0.001$*(PH1I VS BI); $p=0.001$*(PH2I VS PH1I), Cutlery/Straw [$p=0.006$*(PH1I VS BI);$p=0.007$*(PH2I VS BI), and the average weight of trash bags [$p=0.002$* (PH1I VS BI); $p=0.004$*(PH2I VS PH1I)] were statistically significant after the interventions. Therefore, the study concluded that environmental awareness, self-accountability, and education are effective in controlling single-use plastic and paper products and reducing trash generation.

Introduction

The environmental and health impacts of solid waste generation, microplastics from plastic products, paper waste, and other pollutants are extensive. These waste products contribute to various environmental and health consequences, including pollution, climate change, ecosystem degradation, and direct health risks to humans from chemical exposures and pollution-related diseases. Solid waste generation leads to significant environmental pollution, as improper disposal and accumulation of waste can contaminate soil, water, and air (Landrigan et al., 2018).

Due to increased production, solid waste generation, such as trash that includes plastics and paper products, has become critical for the environment and public health. According to the United Nations Environmental Programme (UNEP) Global Waste Management Outlook 2024, municipal solid waste generation is predicted to grow from 2.1 billion to 3.8 billion tonnes from 2023 to 2050 (UNEP, 2024). According to the United States Environmental Protection Agency (EPA), the amount of trash generated in the United States reached approximately 292.4 million tons in 2018, highlighting the urgency of addressing waste management practices (USEPA, 2018). While solid waste management is constantly being addressed to reduce environmental pollution, it is essential to tackle the problem from the roots of per capita waste generation. Reports show that high-income countries like the United States contribute enormous amounts of solid waste to land and oceans despite the robust waste management systems (Law et al., 2020). This is due to the large coastal populations and high per capita waste generation. The US also produces an enormous amount of plastic waste in the world and has the most significant annual per capita plastic waste generation (>100 kg), followed by other highly populated countries like India and China (Kaza et al., 2018; USEPA, 2019). With growing concerns about environmental degradation and the consequences of solid waste accumulation, there is a critical need to raise awareness and explore strategies for mitigating pollution levels at an individual level.

Solid waste generated individually and municipally contributes a menace to the environment in varying degrees. Worthy of note is the particularly insidious threat that microplastics from plastic products pose. These tiny plastic particles can persist in the environment for centuries, accumulating in oceans, rivers, and soil (Hammer et al., 2012, Landrigan et al., 2020). They are ingested by marine life and other wildlife, leading to the bioaccumulation of toxins up the food chain, ultimately affecting human health through the consumption of contaminated seafood and water. Additionally, microplastics can cause physical harm to organisms, disrupt endocrine systems, and carry harmful pathogens and pollutants (Jambeck et al., 2015). Although paper waste is often considered less toxic and biodegradable, it also contributes to environmental degradation. Recycling paper, although beneficial in reducing waste and conserving resources, is not without its environmental costs. Recycling requires energy and water, and the de-inking process can produce sludge that must be managed carefully to avoid environmental contamination. In addition, not all paper products are recyclable, especially those contaminated with food waste or coated with plastic, leading to more waste ending up in landfills (USEPA, 2019). The chemicals used in producing plastics and paper, such as bisphenol A (BPA) and various bleaching agents, can be toxic, leading to severe health issues, including cancer, endocrine disruption, and reproductive health illnesses. BPA, commonly found in reusable plastic water bottles, is known for its ability to mimic estrogen, leading to hormonal imbalances and associated health problems such as polycystic ovarian syndrome, hypothyroidism, and liver function abnormalities (Hengstler et al., 2011). Similarly, the bleaching agents used in paper production can release harmful substances into the environment, which may cause adverse health effects when humans are exposed. Polychlorinated biphenyls (PCBs) are additives commonly used in plastic production and have been indicated in the proliferation of reproductive disorders in humans, altered hormone levels, and contamination of aquatic life even at minimal concentrations (Alabi et al., 2019). Another pollutant is methane gas - a potent greenhouse gas that exacerbates climate change and is a byproduct of organic waste decomposition in landfills. In landfills, the anaerobic decomposition of organic materials, including paper waste, produces methane, which has a global warming potential many times greater than carbon dioxide over a brief period. This makes managing organic waste critical in mitigating climate change impacts (USEPA, 2021).

Exposure to pollutants from waste further exacerbates health risks. Chemicals released during the breakdown of plastics and paper can contaminate air, water, and soil, leading to various health issues. Respiratory problems are common in areas with prominent levels of air pollution, often resulting from the incineration of waste or the release of volatile organic compounds from decomposing materials. Cardiovascular diseases are also linked to prolonged exposure to environmental pollutants, which can lead to inflammation and other adverse health outcomes (Landrigan et al., 2018; USEPA, 2018).

Research indicates that promoting healthy behaviors and reinforcing existing practices can be effectively achieved by applying research-based strategies and targeted interventions. In addressing the environmental impacts of pollution, public awareness campaigns and educational programs are critical in influencing how individuals use and dispose of potential pollutants. By fostering a deeper understanding of environmental issues and encouraging behavior change, such interventions can play a pivotal role in mitigating the negative effects of environmental pollution on ecosystems (Orji et al., 2018).

Therefore, this pilot study aims to understand how changes in individual behaviors can reduce the overall volume of solid waste produced by examining daily waste generation habits and the effectiveness of educational interventions. The research also seeks to identify practical ways to encourage more sustainable practices. This includes promoting waste reduction, increased recycling, and the adoption of more environmentally friendly consumption patterns.

Method

Study Design

The research employs a multi-year repeated cross-sectional study design to systematically track and analyze waste generation among students over several semesters. The study was conducted from Fall 2020 to Spring 2023, a total of six semesters. This study involves collecting data from students each semester, allowing for the assessment of temporal trends and variations in waste generation patterns. The data collection methodology involves students actively participating in the study by tracking their daily waste generation over an entire semester. Each student is provided with a standardized data log sheet at the beginning of the semester to ensure consistency and accuracy in data recording. The log sheet includes fields for various types of waste (e.g., recyclables, compostables, non-recyclables) and requires students to log the quantity or number of waste items generated each day. (See the Attached Appendix). This hands-on approach gathers valuable data and raises students' awareness of waste-generation habits (Figure 1).

Three distinct behavioral activities were used for data collection:

- Tracking plastic products such as grocery bags, produce bags, other bags made of plastic, and single-use plastic such as food containers, straws, and forks.
- Tracking single-use paper products such as toilet paper and paper towels.
- Solid waste management by tracking the amount of trash and recyclables.

The study aims to educate students about waste management and sustainability practices. By involving them directly in the data collection process, students become more aware of their waste generation habits and the broader implications of waste management. This hands-on experience enhances a deeper understanding of sustainability issues. It encourages students to adopt more environmentally responsible behaviors, contributing to the overall goal of promoting sustainable practices within the community.

Institutional Review Board

This research project was approved by the University's Institutional Review Board (IRB), Protocol 21-010. The study involves the voluntary participation of students who will track their daily waste production over a semester using standardized data log sheets provided at the beginning of the term. At the end of the semester, the instructor emailed all students who completed the semester project, requesting their permission to use the collected data for this research. An informed consent form was included in the email, which is essential for approving the release of their data for further analysis. If students do not consent to release their data, the instructor will exclude it from the study.

Data Collection and Analysis

At the beginning of the semester, the instructor provided a detailed methodology for the semester project, outlining the objectives and procedures. A standard data log sheet was distributed to each student to ensure consistency in the data collection strategy, and this log sheet was also shared in an online folder for easy access and real-time updates. Students had to enter their daily waste generation data in real-time into the log sheet.

The instructor worked closely with each student throughout the semester to refine their data collection methodology and ensure accurate and consistent data recording. As our goal is to find the long-term effect of the intervention on waste management, we recognize that initial enthusiasm and commitment often wane over time. When we learn something new, we are typically excited and dedicated for the first few weeks, but maintaining consistency becomes challenging as time progresses. Therefore, we aim to evaluate the long-term effectiveness of general education about waste generation and management. To achieve this, we divided our data into three time points:

i. Before the intervention (BI), from Week 1 to Week 5 (W1-W5)
ii. Phase 1- Five weeks after the intervention (PH1I), from Week 6 to Week 10 (W6-W10), and
iii. Phase 2- Four weeks after the Phase 1 intervention (PH2I), from Week 11 to Week 14 (W11-W14).

This division allows us to analyze the immediate impact of the intervention as well as its sustained effectiveness over a longer period. During the pre-intervention phase, students maintained their usual daily routines and collected data on their waste generation. In the post-intervention phase, students adopted best practices to limit their waste generation sustainably, implementing strategies learned through educational interventions. This approach allowed for a comparative analysis of waste generation before and after adopting sustainable practices. The study used an MS Excel program for data entry and then R version 4.4.1 for the statistical analysis. Data were tested for outliers and violations of normality and sphericity assumptions. The Shapiro-Wilk normality test and Mauchly's test of sphericity were employed to assess these assumptions. In cases where extreme outliers were detected, a log transformation was applied to the data to mitigate their impact and meet the necessary assumptions for further analysis.

Repeated measures ANOVA (RM-ANOVA) was used to determine whether the mean or log-transformed means of waste generated significantly differed across the three-time points (BI, PH1I, PH2I). Paired t-tests were conducted to compare all possible pairs of different time points. In cases where normality was violated, Friedman's test was used to assess significant differences between the distributions of the groups (time). The Wilcoxon Signed Rank test was employed for matched-pair comparisons of the groups.

In cases of violating the sphericity assumption, the Greenhouse-Geisser correction was applied. This correction adjusts the degrees of freedom for the F-distribution in RM-ANOVA to account for the violation of sphericity. The significance level was set at 0.05. For pairwise comparisons, significance levels were adjusted using the Bonferroni correction (i.e., 0.05 / 3 = 0.017). If a log transformation was applied, all statistical analyses were conducted on the transformed data.

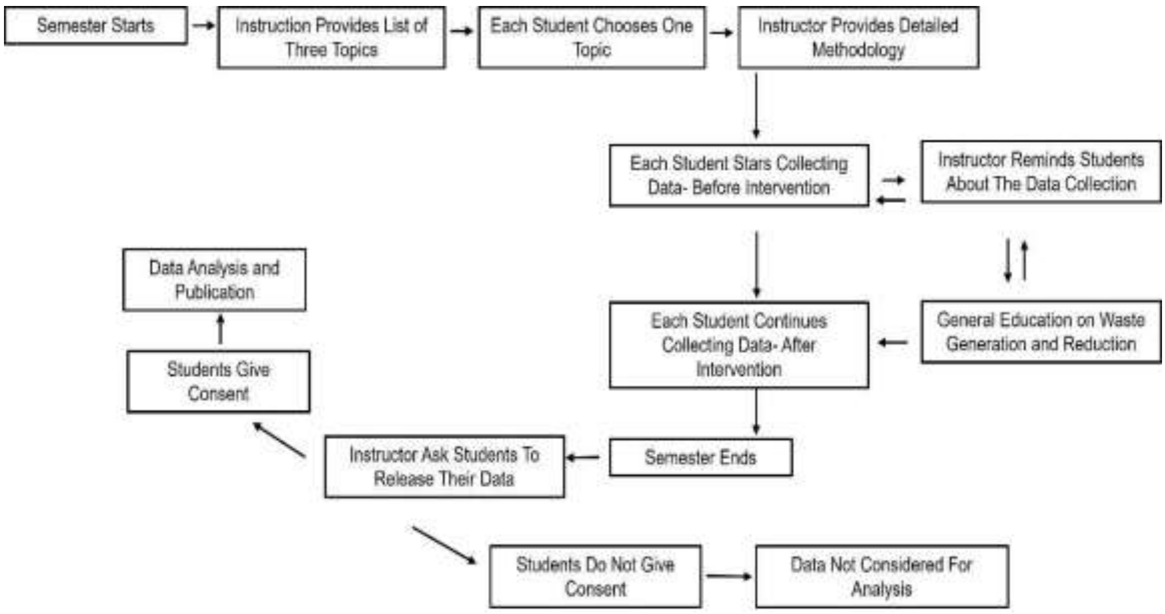

Figure 1. Flowchart of the research design

Results

The data used in this study were collected from students enrolled in the Fall 2020 to Spring 2023 semesters. 109 students took the class over six semesters, and 34 consented to use their data for this study. Each semester, students were asked to track plastic products such as grocery bags, produce bags, other plastic bags, and single-use plastics like food containers, straws, and forks. They were also asked to track paper products such as paper towels and toilet paper. Additionally, they tracked the amount of trash, the number of trash bags, and recyclables for solid waste generation. 12 participants tracked single-use paper products, 11 tracked single-use plastic products, and 11 tracked solid waste generation.

Testing for Outliers, Normality, and Sphericity

After separating our data into three intervention groups (BI, PH1I, PH2I) based on our research questions, we analyzed the descriptive statistics for each group. All waste types in Table 1 had outliers, including extreme outliers. We considered these outliers to be natural and retained them in the dataset. We applied a log transformation for waste types with extreme outliers and violations of the normality assumption. If outliers were still present after transformation, we performed the analysis both with and without the outliers and compared the results. In all cases, we observed the same conclusions. We then checked the normality and sphericity assumptions for each type of waste. The results (P-values) of the Shapiro-Wilk normality test (S) and Mauchly's test of sphericity (M) are presented in Table 1 for each group.

The data for single-use produce bags, cutlery and straws, toilet paper, pounds of trash, and the number of trash bags satisfied the normality assumption but did not satisfy the sphericity assumption. Therefore, we applied one-way RM-ANOVA with Greenhouse-Geisser sphericity correction. Additionally, the PH1I group for single-use grocery bags and the BI group for single-use paper towels did not satisfy the normality assumption, with P-values of 0.02 and 0.04, even after log transformation. Consequently, we used the non-parametric alternative to RM-ANOVA, the Friedman test, to check for significant differences between the distributions of the log-transformed waste amounts within groups (time).

Table 1. Shapiro-Wilk normality test (S) and Mauchly's test (M)

Waste type	Tests	BI	PH1I	PH2I
Grocery Bag*	S	0.34	0.02*	0.27
	M	0.08		
Produce Bag+	S	0.11	0.38	0.1
	M	< 0.001+		
Cups and lids+	S	0.58	0.15	0.51
	M	0.26		
Cutlery and straw+	S	0.25	0.26	0.66
	M	0.003+		
Paper Towel*	S	0.04*	0.11	0.39
	M	0.17		
Toilet Paper*	S	0.08	0.23	0.38
	M	0.007*		
Pounds of Trash*	S	0.85	0.25	0.48
	M	0.03*		
No. of Trash bag*	S	0.22	0.14	0.27
	M	0.002*		

*P- values obtained from log-transformed data
+P-value obtained from original data

Single-Used Paper Products

This study analyzed two types of paper waste generated in common households: toilet paper and paper towels. Twelve subjects were included and divided into three timeline data point groups (BI, PH1I, PH2I). Figure 2 shows the average waste generated from single-use paper products each week. The average weekly waste of single-use paper towel sheets for each person was approximately 37 during the study period. In contrast, each person's average weekly waste of single-use toilet paper sheets was approximately 107.

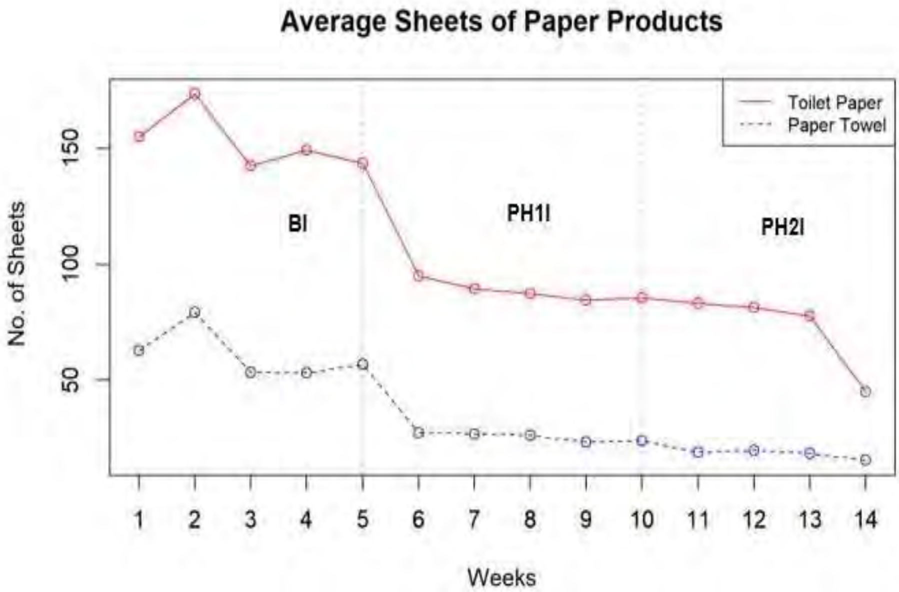

Figure 2. Average sheets of paper products

Table 2 presents the mean and 95% confidence interval for the waste generated from single-use paper products for the BI, PH1I, and PH2I groups. The normality assumption for toilet paper waste was satisfied after log transformation; however, the sphericity assumption was not. Thus, RM-ANOVA with Greenhouse-Geisser correction revealed a significant difference between the mean log number of sheets of toilet paper across the three data points BI, PH1I, and PH2I (P-value < 0.001). Since normality was not satisfied even after log transformation for one of the three groups of toilet paper waste, the Friedman test was applied. It revealed statistically significant differences between the distributions of the three paired groups (BI, PH1I, PH2I) (P-value < 0.001).

Table 2. Intervention effects on single-use paper products

Waste Type		BI	PH1I	PH2I	P-value
Paper Towel	Mean	129.78	51.72	22.71	P < 0.001‡
	95% CI	(44.11, 378.14)	(15, 166.8)	(6.62,77.91)	
Toilet Paper	Mean	328.95	136.62	80.50	P < 0.001*
	95% CI	(106, 1015.70)	(39.44, 473.25)	(23.02, 281.52)	

All results are obtained from back transformation.
*P-value is given for RM-ANOVA with Greenhouse-Geisser sphericity correction.
‡P-value is given for Friedman's test.

Given the significant differences between groups for both types of waste—paper towels and toilet paper—we performed pairwise t-tests and Wilcoxon signed-rank tests to identify which groups differed. The results are presented in Table 3, which shows statistically significant differences in waste generation for paper towels and toilet paper between the following time points: BI and PH1I, BI and PH2I, and PH1I and PH2I (P-value < 0.017). The mean waste generation for paper towels was 60% lower during PH1I than BI. For PH2I, the mean waste generation declined 83% compared to BI and 56% compared to PH1I. Similarly, the mean waste generation PH1I for toilet paper was 58% lower than BI. For PH2I, it was 75% lower than BI and 41% lower than PH1I. Therefore, education on waste generation/management proved to be very effective in controlling the use of single-use paper products.

Table 3. Pairwise comparison between groups for single used papers

Single-use paper products		PH1I VS BI	PH2I VS BI	PH2I VS PH1I
Paper Towel	Mean difference	0.40	0.17	0.44
	P-value‡	<0.001*	<0.001*	0.009*
Toilet Paper	Mean difference	0.42	0.25	0.59
	P-value*	0.003*	0.001*	<0.001*

All results are obtained from back transformation.
P-values* are obtained from paired t-tests.
P-values‡ are obtained from pairwise Wilcoxon signed-rank tests.
All the P-values are adjusted Using the Bonferroni Multiple Testing correction method.

Single-Use Plastic Products

This study analyzed four types of plastic waste generated in common households: grocery bags, produce bags, cups and lids, and cutlery and straws. Eleven subjects were divided into three data points (BI, PH1I, and PH2I). Figure 3 shows the average waste generated from single-use plastic products each week. The average weekly use of single-use grocery bags per person was approximately six, single-use produce bags were about three, and single-use cups and lids were approximately three, as was the single-use cutlery and straws per person during the study period.

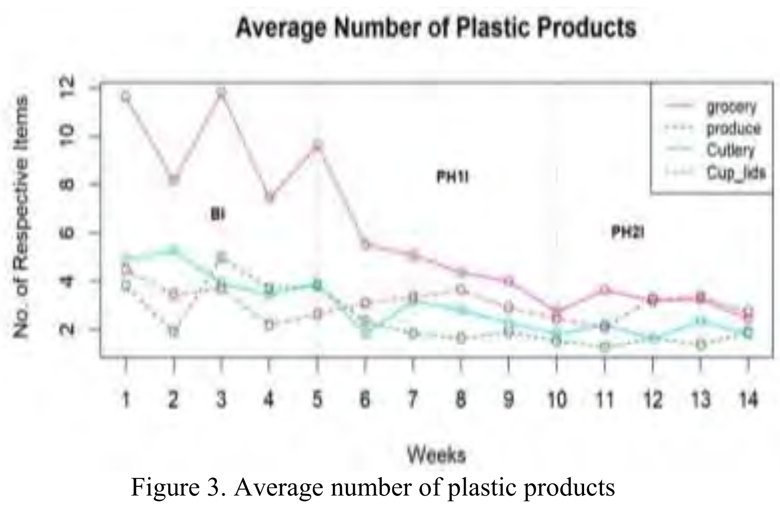

Figure 3. Average number of plastic products

Table 4 presents the mean and 95% confidence interval for the waste generated from single-use plastic products for the groups BI, PH1I, and PH2I.

Grocery Bags: The normality assumption was not satisfied for grocery bags even after log transformation for one of the three groups, so the Friedman test was applied. This test revealed statistically significant differences between the distributions of the paired groups BI, PH1I, and PH2I, with a p-value of <0.001.

Cups and Lids: The normality and sphericity assumptions were satisfied for cups and lids waste, so RM-ANOVA was performed to check for significant differences between the means of the three groups (time points). The difference was not substantial, with a p-value of 0.21.

Produce Bags, Cutlery, and Straws: After the log transformation, the normality assumption was satisfied for the produce bags, cutlery, and straws, but the sphericity assumption was not. Therefore, RM-ANOVA with correction was applied, indicating significant differences between the mean numbers of produce bags, cutlery, and straws across the three groups, with p-values of 0.03 and 0.01, respectively.

Table 4. Intervention effects on single-use plastic products

Waste type		BI	PH1I	PH2I	P-value
Grocery Bag†	Mean	40.29	12.18	8.41	P< 0.001†
	95% CI	(26.52, 60.94)	(4.20, 32.37)	(3.66, 18.01)	
Produce Bag	Mean	18.27	9.27	6.18	0.03*
	95% CI	(8.20, 28.34)	(5.57, 12.98)	(2.77, 9.59)	
Cups and lids	Mean	16.45	15.45	11.45	0.21‡
	95% CI	(9.34,23.57)	(5.71, 25.20)	(5.14, 17.77)	
Cutlery and straw	Mean	21.45	11. 91	8.00	0.01*
	95% CI	(11.93, 30.97)	(6.51, 17.31)	(3.89, 12.11)	

†Results are obtained from back transformation. †P-value is given for Friedman's test.
*P-value is given for RM-ANOVA with Greenhouse-Geisser sphericity correction.
‡ P-value is given for RM-ANOVA.

Table 5 shows statistically significant differences between mean log waste generated from single-use plastics. Grocery Bags: There were statistically significant differences in the mean log waste generated from single-use grocery bags (P-value < 0.017), with a 58% reduction in mean usage five weeks post-intervention (PH1I) compared to before the intervention (BI) and a 29% reduction nine weeks post-intervention (PH2I) compared to PH1I. However, the difference from BI to PH2I was insignificant (P-value = 0.08) despite a 71% decrease in mean waste production.

Table 5. Pairwise comparison between groups for single-use plastic

Single-use plastic products		PH1I VS BI	PH2I VS BI	PH2I VS PH1I
Grocery Bag	Mean difference*	0.32	0.23	0.71
	P-value*	0.001*	0.08	0.001*
Produce Bag	Mean difference+	9.0	12.10	3.10
	P-value$^+$	0.06	0.02	0.05
Cups and lids	Mean difference+	1.0	5.0	4.0
	P-value$^+$	0.78	0.11	0.1
Cutlery and straw	Mean difference+	9.56	13.45	3.91
	P-value$^+$	0.006*	0.007*	0.05

Mean differences* are obtained from back transformation.
Mean difference+ are obtained from original data/without data transformation.
P-values* are obtained from pairwise Wilcoxon signed-rank tests.
P-values$^+$ are obtained from paired t-tests.
All P-values are adjusted Using the Bonferroni Multiple Testing correction method.

Produce Bags: The RM-ANOVA with Greenhouse-Geisser sphericity correction indicated a significant difference in the mean waste generated from produce bags among the three groups. However, pairwise t-tests after correction were non-significant (P-value > 0.017): P-value = 0.06 for PH1I vs. BI, P-value = 0.02 for PH2I vs. BI, and P-value = 0.05 for PH2I vs. PH1I. This may be due to the increased stringency of the correction, a smaller effect size, or a small sample size in the individual comparisons.

Cups and Lids: The results showed a mean percentage decline of 6% from BI to PH1I, 30% from BI to PH2I, and 26% from PH1I to PH2I. Both the non-significant repeated measures ANOVA (P-value > 0.05) and non-significant pairwise t-tests (P-value > 0.017) indicate no significant differences between the means of groups BI, PH1I, and PH2I. This suggests that the educational intervention did not significantly affect the use of cups and lids.

Cutlery and Straw: There were statistically significant differences in mean waste generation from single-use cutlery and straws between BI and PH1I and between PH2I and BI (P-value < 0.017), with a mean percentage decrease of 45% and 63%, respectively. However, there was no statistically significant difference between PH2I and PH1I, with a mean percentage decline of 33%. This indicates that education on waste management had a short-term effect on reducing waste from cutlery and straws but was ineffective in the long term.

Solid Waste Generation

In this study, we analyzed two types of waste generated in common households: the number and weight of trash bags. Eleven subjects were included and divided into three different time points (BI, PH1I, and PH2I). Figure 4 shows the average number and weight of trash generated each week. The overall average weekly waste generated from trash bags per person was approximately four bags, while the overall average weekly weight of trash generated per person was approximately thirteen pounds.

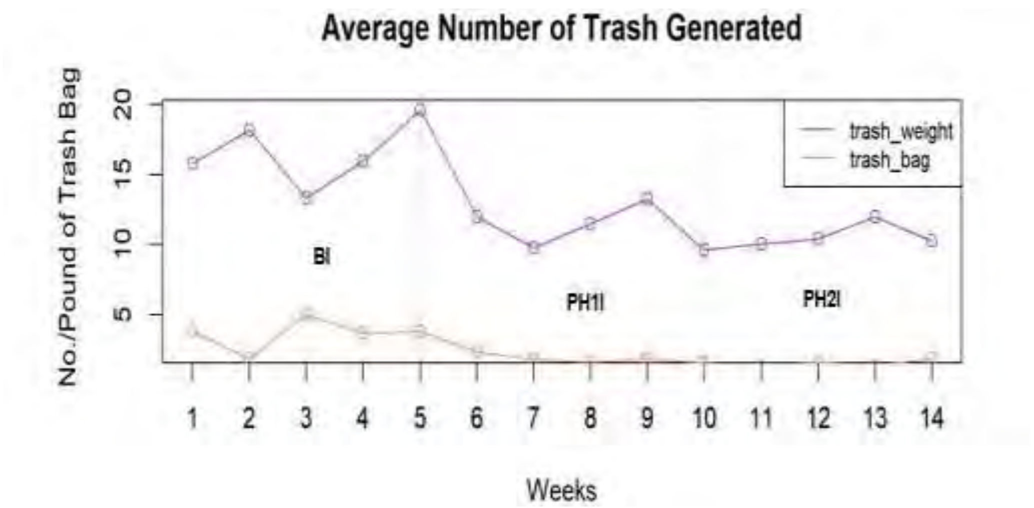

Figure 4. Average number/pound of trash generated

Table 6 presents the mean and 95% confidence interval for the waste generated from the number and weight of trash bags before intervention (BI), five weeks post-intervention (PH1I), and nine weeks post-intervention (PH2I). The normality assumption was satisfied after the log transformation of the number and weight of trash generated, but the sphericity assumption was not. Thus, RM-ANOVA with correction was applied, revealing significant differences between the mean log number of trash bags and the mean log weight for the groups BI, PH1I, and PH2I, with P-values of 0.02 and 0.003, respectively.

Table 6. Intervention effects on number and pound of trash

Waste type		BI	PH1I	PH2I	P-value
Weight of Trash	mean	70.40	41.67	27.50	0.003*
	95% CI	(46.09, 107.53)	(22.67, 76.67)	(13.03, 58.04)	
No. of Trash bag	mean	13.89	11.12	7.49	0.02*
	95% CI	(7.23, 26.71)	(6.22, 19.86)	(4.61, 12.17)	

All results are obtained from back transformation.
The P-value* is given for RM-ANOVA with Greenhouse-Geisser sphericity correction.

Given the significant differences between groups, we performed pairwise t-tests to identify which groups differed, and the results are shown in Table 7. Number of Trash Bags: The results indicated that the mean number of trash bags generated was 20% lower in PH1I and 46% lower in PH2I than BI. Additionally, the mean number of trash bags generated in PH1I was 48% lower compared to PH2I. However, these differences were not significant in pairwise comparisons using the t-test after adjusting for multiple comparisons (P-value > 0.017).

Weight of Trash Bags: There were statistically significant differences in the mean log weight of trash bags (P-value < 0.017), with 41% less mean waste generated in PH1I compared to BI and 34% less mean weight in PH2I compared to PH1I. However, there was no significant difference in the mean log weight of trash bags from BI to PH2I (P-value = 0.05), even though there was a 61% decline in the mean weight of trash bags generated in PH2I compared to BI.

Table 7. Pairwise comparison between groups for number/pound of trash

Trash Generated		PH1I VS BI	PH2I VS BI	PH2I VS PH1I
Weight of Trash	Mean difference	0.59	0.39	0.66
	P-value	0.002*	0.05	0.004*
No. of Trash Bags	Mean difference	0.80	0.54	1.48
	P-value	0.04	0.02	0.03

All results are obtained from back transformation.
P-values are obtained from paired T-tests and were adjusted using the Bonferroni Multiple Testing Correction Method.

Discussions and Conclusions

Several studies have examined the relationship between behavioral activities and environmental pollution. Individual behaviors, such as recycling and composting practices, significantly influence the amount of waste produced. Similarly, eco-friendly behaviors like reusable bags and containers can minimize environmental harm (Smith et al., 2017; Jones & Brown, 2019). Environmental education interventions (EEI) are essential in reducing waste generation and fostering pro-environmental behaviors. A study conducted among students at an academic public health institution indicated that waste generation dropped by 60.1% from the baseline measurement. The EEI program was particularly effective among women and graduate students, who significantly reduced their use of multilayer packaging and non-ecological materials (Torres-Pereda et al., 2020). Similar results were observed in our study, where students significantly reduced their waste generation following the behavioral change intervention through environmental education.

This study found that the mean number of trash bags generated was 20% lower during five weeks post-intervention (PH1I) compared to before the intervention (BI) and 46% reduction nine weeks post-intervention (PH2I) than before intervention (BI). We did not find a statistical significance in the mean number of trash bags generated in PH1I compared to PH2I. This means there is an effect in the first intervention but not during the second intervention for the number of trash bags generated. Similarly, the mean log weight of trash bags was 41% less waste generated in PH1I compared to BI and 34% less mean weight in PH2I compared to PH1I. However, there was no significant difference in the mean log weight of trash bags from BI and PH2I. This also showed that the long-term effects of intervention were challenging to maintain.

This study also found a significant reduction in the use of single-use paper towels and toilet paper between BI, PH1I, and PH2I, with a p-value of less than 0.001. When we compared the mean waste generation of each pair, the results indicated that the mean waste generation for paper towels was 60% lower during PH1I than BI. PH2I, the mean waste generation, declined 83% compared to BI and 56% compared to PH1I. Similarly, the mean waste generation PH1I for toilet paper was 58% lower than BI. For PH2I, it was 75% lower than BI and 41% lower than PH1I. Therefore, education on waste generation/management proved to be very effective in controlling the use of single-use paper products.

This study also analyzed single-use plastic products such as grocery bags, produce bags, cups and lids, cutlery, and straws. We found statistically significant differences in the mean log waste generated from single-use grocery bags with a P-value less than 0.017, with a 58% reduction in PH1I compared to BI and a 29% reduction in PH2I compared to PH1I. However, the difference between mean log waste generated among BI to PH2I was insignificant. This means the effect of the intervention did not last long for single-use plastic grocery bags. For single-use plastic produce bags, we found significant difference in the mean waste generated from produce bags among the three groups: BI, PH1I, and PH2I but there was not any difference between pairwise comparison. There were statistically significant differences in mean waste generation from single-use cutlery and straws between BI and PH1I and between PH2I and BI with a mean percentage decrease of 45% and 63%, respectively. However, there was no statistically significant difference between PH2I and PH1I, with a mean percentage decline of 33%. This indicates that education on waste management had a short-term effect on reducing waste from cutlery and straws but was ineffective in the long term. We did not find significant evidence of a reduction in mean waste generated from cups and lids among BI, PH1I, and PH2I. This suggests that the educational intervention did not significantly affect the use of cups and lids.

Environmental education positively impacts students' knowledge and attitudes toward waste segregation. Studies indicate that students exposed to environmental education develop a more positive attitude toward waste segregation than those not (Erhabor, 2023). Community-based initiatives also play a key role in promoting sustainable behaviors and reducing waste generation. Educational campaigns and policy interventions encourage individuals to adopt environmentally responsible practices. Existing literature suggests that changing behavioral activities can reduce environmental pollution by addressing individual waste generation patterns. Strategies such as recycling, composting, and adopting eco-friendly consumer choices have contributed to mitigating solid waste accumulation and promoting environmental sustainability (Green et al., 2020; Steg et al., 2005; Pham et, al., 2023). However, further research is needed to assess the long-term effectiveness of these interventions and identify additional measures for enhancing environmental awareness and action. In summary, we found that environmental education positively impacts students' knowledge and attitudes toward waste generation and management. However, it is difficult to maintain the motivation to reduce waste management. So, we must frequently provide education on the importance of waste management in daily life.

Recommendations

Based on the findings of this study, it is recommended that educational institutions and policymakers incorporate targeted environmental education programs to reduce solid waste, single-use plastic, and paper waste among students. The significant reduction in waste generation observed through behavioral change interventions underscores the importance of integrating practical, hands-on learning experiences in environmental health curricula. However, in some waste generation, such as single-use plastic produce bags, plastic cups, and lids, we did not have enough evidence to prove if there is any reduction in pairwise comparison between each pair: PH1I vs. BI, PH2I vs. BI, and PH2I vs. PH1I for single-use plastic produce bags. This may be due to the increased stringency of the correction, a smaller effect size, or a small sample size in the individual comparisons. Therefore, further research should focus on expanding the sample size and exploring the long-term impacts of such educational interventions across diverse student populations. Through these collaborative efforts, institutions can be pivotal in cultivating environmentally responsible behaviors, contributing to broader sustainability goals.

Scientific Ethics Declaration

The authors declare that the scientific, ethical, and legal responsibility of this article published in JESEH journal belongs to the authors.

Acknowledgments or Notes

We want to thank all the students who consented to provide their data for this study.

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Appendix

Appendix 1. Sample data collection excel sheet for paper products

	WEEK1						
	[redacted]	D2	D3	D4	D5	D6	D7
How many sheet of paper towel							
How many sheet of toilet paper							
No. of paper napkins							
No. of paper used for printing							
No. of paperboard packaging used for food products such as breakfast cereal							
No. of carton that hold your milk, juice, or similar products							
No. of boxes for shipping products. Example: from amazon or uhaul							
No. of paper cups, plates, and bowl							
No. of sheets of newspaper							
No. of wipes (include pre-moistened wipes)							
Paper sandwich bags							
Others, Please mention							
Others, Please mention							

Appendix 2. Sample data collection excel sheet for plastic products

	WEEK1						
	[redacted]	D2	D3	D4	D5	D6	D7
No. of grocery bags							
No. plastic produce bags							
No. of frozen vegetable bags							
No. of food packaging products (Example: Plastic bags containing Potato Chips, Croutons, Bread and others)							
No. of plastic water bottles, beverage bottles, juice, or milk jars							
No. of plastic takeout containers (clam shell container at work)							
No. of plastic cups and lids (coffee, fountain drink)							
No. of plastic wraps or trashbags							
No. of plastic cutlery and straw							
No. of Ziplock bags (work food baggies)							
No. of plastic rings to hold beverages							
No. of plastic bottle containing Personal Care Products							
No. of disposable coffee pods							
Others , please mention							

Appendix 3. Sample data collection excel sheet for solid waste

	WEEK 1						
	[redacted]	D2	D3	D4	D5	D6	D7
Tracking Solid Waste (Non-recyclable)							
No. of total trash bags generated							
What capacity of trash bag used (in gallons)							
Total pounds of trash generated (measure all trash bags with garbage)							