

Smart Waste Management: An AI-Trainable Trashbin for Optimized Waste Segregation

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Abstract

Waste mismanagement, particularly the improper segregation of trash, is a critical environmental issue that undermines waste processing efficiency and exacerbates pollution. Despite numerous initiatives aimed at promoting waste segregation, many individuals continue to struggle with correctly categorizing waste into biodegradable and non-biodegradable components. This study addresses this challenge by developing the SMARTSEGBIN, an automatic segregation bin designed specifically for classroom environments. The research aims to design and develop an AI-trainable trash bin for classrooms. It also compares the accuracy of SMARTSEGBIN with the manual waste segregation methods. Furthermore, it evaluates the effectiveness of the bin in educating students about waste categorization. The findings reveal that the SMARTSEGBIN utilizes AI technology effectively, achieving high accuracy in distinguishing between biodegradable and non-biodegradable waste. This significant enhancement in accuracy compared to manual segregation methods demonstrates the potential for AI-assisted systems to improve the reliability and efficiency of waste management practices. Additionally, the SMARTSEGBIN proves to be an effective educational tool, resulting in substantial increases in users' ability to identify waste categories, their confidence in making disposal decisions, and their awareness of the environmental impacts of improper waste handling. Engaging with the SMARTSEGBIN not only provides educational benefits but also fosters a culture of responsible waste disposal among students, encouraging sustainable practices that positively impact both the school and the broader community.

Waste; AI-Trainable; segregation; smart bin

1. Introduction

The increasing amount and complication of waste generated by the modern economy presents a significant threat to ecosystems and human health. Every year, an estimated 11.2 billion tons of solid waste is collected worldwide and decay of the organic proportion of solid waste is contributing about 5 percent of

global greenhouse gas emissions. Poor waste management, ranging from non-existing collection systems to ineffective disposal, causes air pollution, water and soil contamination, and transmit diseases (UNep, n.d.).

The Philippines has a continuously rising amount of waste and is expected to further increase in the succeeding years. Government data reveals that around half of the waste produced in the country is biodegradable. On average, Filipinos generate 0.4 kilograms of waste per day, which is less than half of the 0.89 kilograms produced by the Japanese and five times smaller than the 2.2 kilograms generated by Americans (Mantaring, J., 2024). However, non-biodegradable waste, which makes up the largest portion of collected solid waste, presents significant challenges in sorting and storage due to inadequate management and treatment systems (Buencillo et.al, 2023).

Moreover, solid waste management remains a major challenge in the Philippines, especially in urban areas like Metro Manila. Improper waste disposal, inefficient waste collection, and lack of disposal facilities are among the dominant concerns in the country's solid waste management. Metro Manila generates over 10,000 tons of waste every day, and this is expected to double by 2030. In response, the government enacted the RA 9003 or the "Ecological Solid Waste Management Act of the Philippines" to encourage the reduction of waste at source, recovery, recycling and reuse of wastes, creating mandatory targets through the local government units. However, there is a very limited number of materials recovery facilities equipped with technologies to reduce wastes like recycling and composting (Woima, n.d.). Narrowing down, Batangas City generates 167 metric tons of waste daily, which averages about 0.50 kilograms per person. The city manages a centralized waste collection system, subcontracted to Metro Waste Solid Waste Management Corporation. However, many households are located too far from the collection routes, leaving them without access to solid waste management (SWM) services. This has led to illegal dumping, burning of trash, and increasing pollution in local water bodies such as Batangas Bay, the Calumpang River, and the Verde Island Passage. To address these challenges, the Mother Earth Foundation has stepped in to provide technical assistance to Batangas City, aiming to implement a zero-waste approach to solid waste management, including recycling initiatives in 30 of the city's 105 barangays (Grassi et.al 2021).

In addition to addressing solid waste segregation issues, Banaba West Integrated School has implemented active responses to these challenges. Recognizing the necessity for students to have access to freshly cooked meals, snacks, and juices, the school faced difficulties in proper waste segregation and disposal. In response, the school's club organization, the Yes-O club, has established a rule encouraging students to bring eco bags for waste disposal. This initiative aims to streamline waste management and promote responsible habits among students. However, despite this rule, proper segregation of plastics and food waste remains a challenge, as both are still placed in the same bag. Moreover, even with the school's efforts to teach students to segregate biodegradable from non-biodegradable waste, many are still confused about how to distinguish between these types of waste. Some students, either out of haste or frustration, dispose of waste improperly, which makes the traditional segregation bins ineffective. As a result, proper waste management continues to be a challenge.

These challenges have led to the development of various innovations and products in the market designed to address them that are similar to the researcher's output, specifically Bin-e. Bin-e is an AI-based smart waste bin designed for public spaces, aimed at simplifying the recycling process. It automatically sorts and compresses waste, monitors fill levels, and processes data to facilitate efficient waste management.

In line with this, the researcher developed an AI-trainable segregation bin called SMARTSEGBIN. This bin automatically separates biodegradable waste from non-biodegradable waste, ensuring efficient waste management in classrooms. Once the waste is recognized, it is transported to the appropriate compartment, enhancing overall waste segregation practices. This innovation not only sets the SMARTSEGBIN apart but also contributes significantly to improved waste management practices. While the bin automates the segregation process, it simultaneously educates students by allowing them to observe how biodegradable and non-biodegradable waste is separated during the collection process. This interactive experience will equip students with the knowledge to properly dispose of waste in other places, promoting responsible waste management beyond the school environment.

1.1 Statement of the Problem

This study aims to address the problem of waste mismanagement by developing an automatic segregation bin specifically designed for classrooms.

Specifically, this study answer the following questions:

1. How can AI technology be applied to accurately categorize different types of waste?
2. How does SMARTSEGBIN significantly improve waste segregation accuracy compared to manual segregation method?
3. How effective is the SMARTSEGBIN in educating users about proper waste disposal practices?

1.2 Hypothesis

There is a significant difference between SMARTSEGBIN and manual segregation methods of waste segregation

1.3 Conceptual Framework

The conceptual framework for the SMARTSEGBIN project utilizes the Input-Process-Output (IPO) model to systematically illustrate how the AI-trainable trash bin operates to enhance waste segregation in educational settings. By defining the essential inputs, processes, and outputs, this framework provides a structured approach to understanding the integration of technology in waste management practices. The inputs include various data and physical components, as well as the involvement of users. The process focuses on the AI-driven classification and sorting of waste, while simultaneously promoting user education on proper disposal methods. The resulting outputs reflect improved waste segregation accuracy, increased awareness among students, and valuable operational data that can inform future enhancements. This framework not only highlights the functionality of the SMARTSEGBIN but also underscores its significance in fostering sustainable waste management habits within the school community.

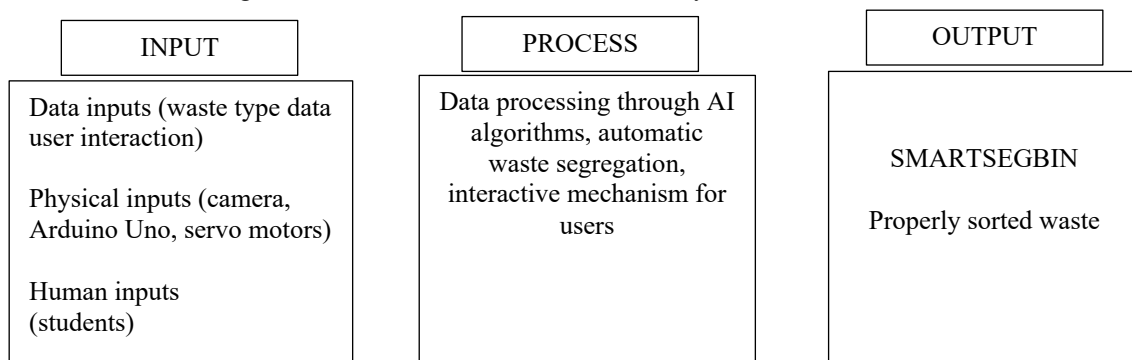


Figure 1. Conceptual Paradigm

1.4. Methods

The SMARTSEGBIN is an AI-trainable segregation bin designed to enhance waste management through real-time sorting and user engagement in classrooms. It employs advanced vision sensors powered by AI to automatically distinguish the material being thrown in the bin. A program will sort between biodegradable and non-biodegradable waste. The system is programmed to provide alerts and feedback to users, encouraging responsible waste disposal practices.

In comparison to traditional non-biodegradable and biodegradable bins, the SMARTSEGBIN stands out due to its automation and user interaction features. Traditional bins typically require users to manually sort waste, often leading to contamination and inefficient disposal. In contrast, the SMARTSEGBIN actively separates waste types, promoting proper segregation without relying solely on user effort.

- Steps in Making SMARTSEGBIN

The development of the SMARTSEGBIN involves a combination of mechanical, electronic, and software components. Developing an AI-trainable segregation bin, referred to as the "SMARTSEGBIN", will follow a clear and organized process. Below is a step-by-step guide:

- 1.Design the Bin

Create the physical design of the SMARTSEGBIN, focusing on its size, shape, color, and material choices. The design should include two waste compartments, one for biodegradable waste and one for non-biodegradable waste. Ensure the design allows for easy access to the collections of the bins for biodegradable and non-biodegradable wastes, promoting user-friendly interaction.

2. Integrate AI-Powered Camera Sensors

Install AI-powered camera sensors aligned with the flap. This camera will analyze and categorize waste types as biodegradable or non-biodegradable. After the camera detects the waste type, the flap flips which and directs the waste into the correct bin compartment based on the categorization.

3. Power Supply

Connect the SMARTSEGBIN to a power source via a USB connection to a laptop. This allows for continuous power and easy data transfer for monitoring waste sorting in classrooms, making it accessible and efficient for school use.

4. Mechanical and Electrical Assembly. Assemble the physical structure of the SMARTSEGBIN, including the base and storage bins for each waste compartment. Install all electronic components and sensors, ensuring they are securely integrated.

5. Testing and Quality Control. Conduct thorough testing of the SMARTSEGBIN's functionality. Simulate various waste types to ensure the camera sensors accurately detect and categorize the waste. Test the mechanical operation of the latch to confirm proper waste direction and disposal. Address any sensor recognition or flap malfunctions, and fine-tune the system for optimal performance.

How to Use SMARTSEGBIN

Using the AI-trainable segregation bin, known as the "SMARTSEGBIN," is a straightforward process. Here's a step-by-step guide:

- 1.Approach the SMARTSEGBIN. When ready to dispose of waste, walk up to the SMARTSEGBIN. Follow the directions displayed on the front of the bin to guide you through the process.

2. Waste Disposal.The SMARTSEGBIN features an opening on top for waste disposal. Simply deposit your waste into this opening. The bin will then use AI-powered vision camera sensors, mounted near the flap, to detect whether the waste is biodegradable or non-biodegradable.

3. Internal Sorting. Once the waste is detected by the camera, the flap will automatically flips to its respective category whether biodegradable or non-biodegradable bins. The front section of the SMARTSEGBIN is transparent, allowing students to observe how it functions and sorts waste. This helps

familiarize them with the different waste categories. This educates them about proper waste segregation, encouraging them to apply this knowledge in other settings beyond the classroom.

4. Waste Collection. The SMARTSEGBIN is designed with a capacity suitable for one day's worth of waste per classroom.

The SMARTSEGBIN's vibrant green exterior complements the yellow and green walls of the classroom, blending seamlessly with the interior design. Positioned at the back of the classroom, its placement ensures easy access for students. Constructed from durable materials, the SMARTSEGBIN is built to withstand the daily use and demands of a busy classroom environment, ensuring long-lasting performance and reliability.

At the top, an opening allows for easy waste disposal. Integrated AI-powered camera sensors detect the type of waste as it is deposited. Once identified, a flap automatically flips to direct the waste into the appropriate compartment, whether biodegradable or non-biodegradable. This efficient internal sorting mechanism streamlines the disposal process and reinforces proper waste segregation practices among students.

Overall, the SMARTSEGBIN combines modern aesthetics with advanced technology, making it an ideal solution for effective waste management in classroom environments.

• Design of the SMARTSEGBIN

The SMARTSEGBIN consists of a standard trash bin retrofitted with an AI-based camera and sensor system capable of identifying and categorizing waste. The bin's AI model is trained using a supervised machine learning algorithm to recognize different types of waste: biodegradable and non-biodegradable.

• AI Training and Categorization Process

Training Data: Images of various waste items (plastics, papers, food, etc.) were used to train the AI model. The dataset includes over 20 labeled waste items to cover a wide range of classroom waste.

Algorithm: The AI model utilizes proprietary image recognition model by TM for image recognition.

Classification: Once the waste is placed in the bin, the AI categorizes it into biodegradable and non-biodegradable.

• Experiment Design

The study was conducted in two phases:

1. Pre-Implementation: Waste segregation was performed manually in a classroom, and the accuracy of waste classification was recorded.

2. Post-Implementation: The SMARTSEGBIN was installed in the same classroom, and its performance was monitored over two weeks.

The following metrics were measured: Accuracy of waste categorization (manual vs. SMARTSEGBIN).

User engagement and education, measured through pre- and post-surveys to gauge students' awareness of waste categories.

• Data Collection

Data was collected based on number of correctly and incorrectly segregated waste items and students' understanding of waste categories before and after using SMARTSEGBIN.

1.5 Results and Discussions

The Philippines faces significant challenges in managing its waste, particularly in the segregation of biodegradable and non-biodegradable materials. In response, efforts have been made to improve waste management through the development of segregation systems, including specialized bins for sorting biodegradable and non-biodegradable waste.

1. AI Categorization Accuracy

The SMARTSEGBIN was designed with AI to differentiate between biodegradable and non-biodegradable waste items. The AI was trained on a dataset consisting of various waste materials, and its performance was evaluated based on its ability to correctly classify each item into these two categories.

Table 1. AI Categorization Accuracy

Waste Type	Number of Items Tested	Correctly Categorized (%)	Incorrectly Categorized (%)
Biodegradable	10	91%	9%
Non-biodegradable	10	94%	6%
Overall Accuracy	20	92.5%	7.5%

Table 1 presents the AI categorization accuracy in categorizing biodegradable or non-biodegradable wastes. The researcher used 10 biodegradable waste items and 10 non-biodegradable waste items. The AI system correctly classified 91% of biodegradable items. These items, typically organic materials like food scraps, paper, and plant matter, were identified with high accuracy. The slight error rate of 9% could be attributed to materials with ambiguous features, such as certain paper products with coatings or packaging that may confuse the AI. For non-biodegradable categorization, the system showed even higher accuracy in identifying non-biodegradable items, with a 94% success rate. Non-biodegradable waste, such as plastics, metals, and synthetic materials, tends to have more distinct physical characteristics, making it easier for the AI to classify these items correctly.

For overall accuracy, the AI system in the SMARTSEGBIN achieved an overall accuracy of 92.5%, meaning it correctly categorized most items into either biodegradable or non-biodegradable. This indicates that AI technology is well-suited for waste classification based on biodegradability. The AI's high performance in distinguishing between biodegradable and non-biodegradable waste indicates that it effectively learns and applies the physical and visual properties of different materials. For instance, it can identify the texture, color, and composition differences between organic and synthetic items.

The 7.5% error rate across both categories may be attributed to items that possess qualities of both biodegradable and non-biodegradable materials (e.g., paper products with plastic coatings, certain types of packaging). These hybrid materials can be difficult for both humans and machines to classify consistently.

This is similar to the study by Endaya et al., (2020) focuses on the implementation of an automated trash bin with smart compression to effectively separate and compress garbage, their system makes use of push buttons, LEDs, a stepper motor, an ultrasonic sensor, and a linear actuator. The unique aspect of achieving automated waste management rests in the integration of its elements. Through the elimination of manual labor, the reduction of human error, and the efficient use of space within the trash cans, these technologies improve the effectiveness of waste management systems.

2.Comparison of Waste Segregation Accuracy between SMARTSEGBIN and manual segregation method

Table 2

Waste Segregation Accuracy

Method	Correctly Categorized (%)	Incorrectly Categorized (%)
Manual Segregation	65%	35%
SMARTSEGBIN	92%	8%

Table 2 reveals the waste segregation accuracy in categorizing different types of waste using AI technology. It shows that when users manually sorted waste, in 20 items, 13 items or 65% of items were correctly categorized, while 7 items or 35% were misclassified. This highlights a significant margin for error in manual methods, likely due to confusion or lack of knowledge about proper waste categories. The relatively high rate of incorrect categorization (35%) suggests that users often struggle to distinguish between biodegradable and non-biodegradable, which can lead to ineffective waste processing and contamination of waste.

On the other hand, the SMARTSEGBIN, utilizing AI technology, achieved a much higher accuracy rate of 92% or equals to 18 items were correctly categorized, with only 8% or 2 items of the waste items incorrectly categorized. This substantial improvement demonstrates the effectiveness of AI in automating the waste segregation process, reducing human error, and ensuring that more waste is sorted into the correct category.

The significant difference in accuracy between manual segregation and the SMARTSEGBIN suggests that AI-assisted segregation can drastically enhance the efficiency and reliability of waste management. By minimizing incorrect categorizations, the SMARTSEGBIN not only helps in proper waste disposal but also reduces the potential environmental impact caused by improper segregation. The system ensures that waste is processed more accurately, which is critical for recycling and composting efforts.

3. Effectiveness of SMARTSEGBIN in educating users about proper waste disposal practices To evaluate the effectiveness of the SMARTSEGBIN in educating users about proper waste disposal of biodegradable and non-biodegradable waste, a survey was conducted before and after the use of the SMARTSEGBIN in a classroom setting. The survey assessed users' knowledge and awareness of waste categories, their confidence in sorting waste, and their understanding of the environmental impact of incorrect waste disposal.

Table 3 presents the user knowledge and awareness improvement before and after using the SMARTSEGBIN. Before using the SMARTSEGBIN, only 58% of the users could correctly identify biodegradable waste, and 60% could identify non-biodegradable waste. After the implementation of SMARTSEGBIN, these figures increased to 92% for biodegradable waste and 94% for non-biodegradable waste.

Table 3

User Knowledge and Awareness Improvement

Statement	Pre-Survey Awareness (%)	Post-Survey Awareness (%)	Percentage Increase
Ability to correctly identify biodegradable waste	58%	92%	+34%
Ability to correctly identify non-biodegradable waste	60%	94%	+34%
Confidence in properly disposing of biodegradable waste	55%	90%	+35%
Confidence in properly disposing of non-biodegradable waste	57%	91%	+34%
Awareness of the environmental impact of incorrect waste disposal	65%	88%	+23%

This 34% increase in knowledge indicates that SMARTSEGBIN was highly effective in educating users about the correct categorization of waste. By allowing users to observe how waste is automatically sorted, it reinforced their understanding of which items belong in which category.

The users' confidence in disposing of waste correctly also showed substantial improvement. Pre-survey data showed 55% confidence in properly disposing of biodegradable waste, which increased to 90% after using SMARTSEGBIN. Similarly, confidence in disposing of non-biodegradable waste increased from 57% to 91%.

This increase in confidence suggests that the SMARTSEGBIN not only educates users but also empowers them to make better waste disposal decisions. The automatic feedback from the bin helps users learn by doing, leading to greater certainty in their actions.

Awareness of the environmental impact of incorrect waste disposal increased from 65% to 88% after exposure to the SMARTSEGBIN, representing a 23% increase. This demonstrates that the SMARTSEGBIN not only focuses on technical aspects of waste sorting but also contributes to a broader understanding of environmental responsibility.

By automating and explaining the waste sorting process, SMARTSEGBIN underscores the importance of proper waste management for sustainability, thus fostering a more environmentally conscious mindset among users.

The overall improvement in users' knowledge, confidence, and awareness clearly indicates that SMARTSEGBIN is highly effective as an educational tool. Its interactive nature allows users to directly observe the consequences of their actions, which enhances the learning experience. The fact that users gained a stronger understanding of the waste disposal process and its environmental impact after using the SMARTSEGBIN highlights its potential to be a long-term solution for raising awareness about waste segregation.

1.6. Conclusions

1.The AI technology can be applied effectively to categorize waste into biodegradable and non-biodegradable. The level of accuracy is expected to enhance waste segregation practices, reducing human error and leading to more efficient waste management systems. With continued training and refinement, the AI model could further improve its classification accuracy, especially for mixed-material waste items.

2. The significant difference in accuracy between manual segregation and the SMARTSEGBIN suggests that AI-assisted segregation can drastically enhance the efficiency and reliability of waste management.

3. The SMARTSEGBIN is highly effective in educating users about the proper disposal of biodegradable and non-biodegradable waste. It resulted in significant increases in users' ability to correctly identify waste categories, confidence in making disposal decisions, and awareness of the environmental impact of improper waste handling.

1.7. Recommendations

While the SMARTSEGBIN is a promising solution, further enhancements could improve its effectiveness. Challenges such as sensor recognition issues and flap malfunctions indicate areas for refinement. The AI can be trained for further enhancements, including expanding its use to public spaces and integrating advanced features like weight sensors and automated lid mechanisms, which can maximize its impact.

In the future, expanding the use of SMARTSEGBIN to broader environments, such as public spaces, could increase its influence in promoting responsible waste disposal on a larger scale. By collaborating with local governments and businesses, SMARTSEGBIN can be integrated into community waste management programs, encouraging citizens to participate in proper segregation practices. The bin's capacity could be increased to accommodate higher waste volumes in larger areas, promoting more efficient disposal practices for both biodegradable and non-biodegradable materials.

By extending its reach, SMARTSEGBIN has the potential to significantly amplify its impact on waste management. The automatic sorting mechanism and hygiene-focused features, such as automated lid opening, would make it an essential tool in public health, particularly in areas with high foot traffic. This expansion would further raise environmental awareness, making waste disposal an educational and responsible practice for various sectors, not just classrooms in schools.

Moreover, SMARTSEGBIN's influence extends beyond its primary function of sorting waste. By offering an AI-trainable solution, it actively engages individuals in addressing current waste challenges while fostering environmental stewardship. By integrating SMARTSEGBIN into daily routines, the school encourages students to adopt sustainable behaviors early on which ultimately leads to a cleaner and greener environment. SMARTSEGBIN's ease of adoption and potential market reach ensures its usability in different settings, from schools to public spaces.

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Appendix

A.1. Letter to Participants

Date

Dear Participants,

I am reaching out to request your participation in a valuable research project, Smart Waste Management: An AI-Trainable Trash Bin for Optimized Waste Segregation. This study aims to develop an intelligent waste management system that enhances waste sorting efficiency using AI technology. The project focuses on creating a trash bin that can automatically identify and classify various types of biodegradable and non-biodegradable waste. By improving the accuracy of waste segregation, SMARTSEGBIN seeks to promote sustainable waste management practices, reduce landfill contributions, and support environmental conservation efforts through optimized waste disposal. Your insights will play a crucial role in shaping our understanding of these complex interactions and will contribute meaningfully to our research.

To gather your perspectives, we kindly ask that you complete the attached questionnaire. Your responses will remain confidential and will only be used for research purposes. Participation is entirely voluntary, but we believe your experiences and viewpoints will provide invaluable contributions to our findings.

I greatly appreciate your time, effort, and willingness to participate in this project. Together, we can further important research on family dynamics and foster a better understanding of intergenerational care and support systems.

Thank you once again for your participation.

Sincerely,

RAZEL M. FERRER

Banaba West Integrated School

*A.2. Questionnaire***STUDENT CODE:** _____**Effectiveness Survey**

Directions: Please read each question carefully and check(☑) the column that best reflect your answer.

Part 1: Knowledge and Awareness of Waste Categories

	Very Knowledgeable	Somewhat Knowledgeable	Slightly Knowledgeable	Not Knowledgeable
1. Before using the, how knowledgeable were you with the different categories of waste (e.g., biodegradable and non-biodegradable)?				
2. After using the SMARTSEGBIN, how would you rate your knowledge of waste categories?				

Part 2: Confidence in Sorting Waste

	Very Confident	Somewhat Confident	Slightly Confident	Not Confident
4. How confident were you in sorting waste into the correct categories before using the SMARTSEGBIN?				
5. How confident are you in sorting waste after using the SMARTSEGBIN?				

Part 3: Understanding Environmental Impact of Incorrect Waste Disposal

	Very Confident	Somewhat Confident	Slightly Confident	Not Confident
4. How confident were you in sorting waste into the correct categories before using the SMARTSEGBIN?				
5. How confident are you in sorting waste after using the SMARTSEGBIN?				
6. Before using the SMARTSEGBIN, how much did you know about the environmental impact of incorrect waste disposal?				
7. After using the SMARTSEGBIN, how well do you understand the environmental consequences of incorrect waste disposal?				

Part 4: Overall Experience

	Very Satisfied	Satisfied	Neutral	Unsatisfied
8. How satisfied are you with the SMARTSEGBIN's effectiveness in educating users on waste disposal?				