Arduino-based Bottle Reclassification and Vegetable or Flower Seed Equivalency Vendo Machine

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According to National Geographic (2022), agriculture is the art and science of cultivating soil, growing crops, and rearing livestock. It plays a vital role in producing the goods people use daily, such as fruits, vegetables, rice, and other agricultural commodities available in grocery stores. Agriculture relies on various production techniques to generate these essential goods. Over time, technology has become a fundamental component of agricultural production, enabling efficiency and productivity through the use of automated machines that simplify labor-intensive tasks (Abiri et al., 2023; Jiang et al., 2025; Duguma & Bai, 2025; Bazargani & Deemyad, 2024; Padhiary et al., 2025; Chen, 2025; Thilakarathne et al., 2025).

Technological advancements have significantly transformed agriculture and the environment. Machines are now widely used not only to improve productivity in farming but also to support environmental sustainability through waste management and recycling. For instance,

recycling machines that process plastic bottles help reduce environmental waste. As National Geographic (2022) further explained, agricultural products such as food, textiles (cotton, wool, and leather), paper, and timber are central to daily life, and these outputs vary globally depending on climate, geography, cultural practices, and technological capacity. Technology has undeniably revolutionized modern life, influencing nearly every sector, education, business, industry, and especially agriculture. As technology continues to evolve, it becomes increasingly integrated into daily activities and essential operations. Those who fail to adopt technological tools in production processes often find it challenging to remain competitive. Recognizing this, the present study introduces an innovative system called the Arduino-based bottle reclassification and vegetable or flower seed equivalency vending machine, which integrates environmental responsibility with agricultural development. This innovation builds upon an earlier system, Cash and Sanitize: An Arduino-Based Reverse Vending Machine with Automated Hand Sanitizer, and expands its purpose from hygiene promotion to sustainability and agricultural engagement.

The proposed vending machine aims to encourage proper plastic bottle disposal by offering seed packets as a reward. Users deposit a plastic bottle into the machine and can then choose from a selection of visible flower or vegetable seeds displayed behind a transparent glass door. After selecting a category, the machine dispenses the corresponding seed packet into the collection box. This approach not only promotes environmental awareness and recycling but also supports local agricultural activities by providing seeds for planting.

The main objective of this study is to design and implement an efficient, project-based system for collecting plastic bottles through an

automated vending machine that exchanges them for seeds. This initiative seeks to benefit farmers, gardeners, and community residents by fostering a sustainable cycle of recycling and planting, turning waste into resources that support both environmental conservation and agricultural growth.

Theoretical Framework

Environmental Impact of Plastic Waste

The extensive use of plastics in household and commercial products has contributed significantly to environmental degradation. Plastic waste has become one of the most pressing global issues, affecting ecosystems, human health, and the climate (Pilapitiya et al., 2024; Islam, 2025). The United Nations (2018) reports that approximately 8 million tons of plastic waste enter the oceans annually, causing the deaths of around 1 million seabirds and 100,000 marine mammals each year. These statistics highlight the severity of plastic pollution and underscore the urgent need for innovative and sustainable waste management solutions.

Plastic pollution not only impacts marine life but also contributes to broader environmental challenges such as global warming, climate change, and the thinning of the ozone layer. Improper disposal and accumulation of plastics in landfills or natural environments create long-term ecological consequences, including soil contamination and disruption of natural habitats. As the global population continues to rely heavily on plastic products, the environmental burden of plastic waste is expected to increase unless comprehensive mitigation strategies are implemented. The literature emphasizes that addressing plastic pollution requires a combination of policy, technological intervention, and public engagement (Bertolazzi et al., 2024; Alaghemandi, 2024; Matavos-Aramyan, 2024; Pambudi et al., 2025;

Rahman et al., 2025; Tang, 2023; Rohmana et al., 2025).

Technological Innovations in Plastic Waste Management

One of the key technological solutions proposed to mitigate plastic waste is the Reverse Vending Machine (RVM), a system designed to accept plastic bottles in exchange for rewards or incentives. Zia et al. (2022) describe the RVM as a machine where users deposit empty plastic bottles for recycling. The machine performs several automated functions, including bottle acceptance, fill detection, and notifying authorities when the machine is full. By providing tangible rewards, RVMs encourage public participation in proper waste disposal and promote environmental awareness.

Recent innovations have enhanced the RVM concept by integrating automation and digital technology. Modern systems are equipped with microcontrollers and sensors that can identify users, weigh the waste, and convert the weight into redeemable points through RFID-based systems. Such automation reduces the inconvenience of manual recycling, which often requires users to transport large volumes of waste to recycling centers. Studies in Malaysia demonstrate that small-scale testing of automated recycling bins with reward systems increases participation in recycling programs, motivating citizens to engage in environmentally responsible behaviors while simultaneously creating economic opportunities through the "waste-to-wealth" concept (Tomari et al., 2017; Hassan et al., 2000). These technological solutions represent a practical and scalable method for addressing urban waste management challenges.

Agricultural Development and Sustainability

Agriculture, defined as the art and science of cultivating soil,

growing crops, and raising livestock, forms the backbone of human civilization. It encompasses all processes involved in producing food, fiber, and raw materials necessary for human life. Farming, a core aspect of agriculture, involves the careful management of crops and livestock to provide sustenance, clothing, and other essential resources. Over thousands of years, agriculture has shaped cultures, economies, and societal structures, influencing traditions and values while providing the foundation for civilizations worldwide.

In the Philippines, agriculture remains a crucial sector due to the country's abundant natural resources. However, urbanization, industrial development, and climate change have reduced the availability of arable land, disrupted crop production, and contributed to the inflation of agricultural commodities. These challenges highlight the need for innovative agricultural practices and interventions that enhance sustainability, improve access to essential resources, and ensure the availability of crops for both market and personal use. Promoting agriculture as a sustainable practice is vital not only for economic growth but also for food security and community development.

Integration of Technology and Agriculture through Incentive Systems

Technological innovations in environmental management, such as reverse vending machines, can be effectively integrated into agriculture to address both ecological and economic challenges. By exchanging recyclable materials like plastic bottles for agricultural incentives, such as vegetable or flower seeds, these systems encourage recycling while simultaneously promoting crop cultivation. This dual-purpose approach provides households, gardeners, and farmers with accessible seeds that can be used for personal consumption or commercial production, thereby

enhancing crop availability and contributing to local food security.

The Arduino-based bottle reclassification and vegetable or flower seed equivalency vending machine exemplifies the synergy between technology and agriculture. This innovation converts plastic waste into a valuable resource for agricultural use, encouraging environmental responsibility and sustainable farming practices. By linking waste management with agricultural productivity, the system creates a circular economy in which recycling supports community development, environmental conservation, and food production. Such integrated initiatives demonstrate that technological interventions can simultaneously address multiple societal challenges, making them highly relevant in modern sustainability and agricultural strategies.

Research Framework

The data collected in this study served as the foundation for developing and evaluating the system.

Data

Table 1 presents the characteristics of the primary materials used in the system project, specifically the plastic bottles and seeds.

Table 1

Characteristics of the primary materials

Data Set	Characteristic
Plastic Bottle	Made of Polymers
Seeds	Plants and Vegetables

The plastic bottles are made of polymers, while the seeds consist of

various plant and vegetable types. Understanding these characteristics is essential for the system to function effectively.

Method

   The data for this study were collected through a survey administered to 30 respondents. The total number of respondents was determined using Slovin's formula, which also guided the application of a random sampling method for distributing the survey questionnaires. The survey instrument was designed to assess three key aspects: functionality, environmental impact, and profitability.

   To measure respondents' perceptions, the researchers employed a four-point Likert scale, which included the following response options: strongly agree, agree, disagree, and strongly disagree. Each participant used this scale to indicate their level of agreement with each survey item. This approach allowed the researchers to quantify opinions consistently and analyze the data systematically, ensuring that the findings accurately reflect the respondents' views on the system's functionality, environmental contribution, and profitability.

Ethical Considerations

   The study prioritized ethical and safe use of the system throughout the study. Ensuring the functionality, usability, and compatibility of the system was a key requirement before deployment. The system underwent thorough testing to confirm that it operates correctly and reliably, minimizing the risk of errors during user interaction.

   Additionally, the system was designed to be user-friendly, with a clear manual provided to guide users in its operation. A backup mechanism

was also included to address potential technical issues and reduce inconvenience for users. Regular monitoring and verification of the system's processes were conducted to ensure that it consistently meets its intended goals. These precautions are essential not only for the researchers' accountability but also to safeguard the experience and safety of end-users, guaranteeing smooth and error-free system operation.

Experimental Design

An experimental design was developed to guide the implementation of the study. This design outlines the study's objectives and demonstrates the logical flow of the research process. The researchers employed a repeated measures design, in which the same respondents participate in each condition of the vending machine experiment. This approach ensures that each condition is evaluated consistently by the same participants, who include farmers, gardeners, and residents.

Modeling

Selecting an appropriate model is a critical factor for the system's effectiveness, as it determines how testing is conducted and which techniques are most efficient. For this study, the researchers employed the prototyping method to develop the system. This approach allows for constructing a preliminary version of the system, which can be tested and refined before final production.

The prototyping method is particularly effective because it enables the identification and resolution of potential issues early in the development process. By iteratively testing and improving the system, the researchers can ensure that the final product is functional, reliable, and user-friendly. This method not only enhances the quality of the system but also reduces

the likelihood of errors during deployment.

Figure 1

Prototyping model
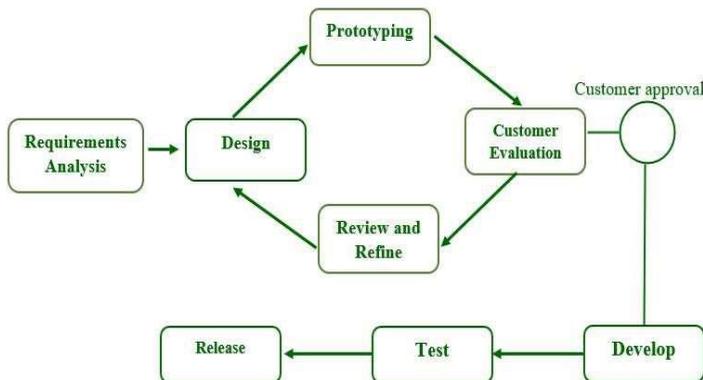
Procedures of the Different Phases

Design. The design phase focuses on creating the overall blueprint of the Bottle Reclassification Vending Machine. This includes outlining the system architecture, interface, and other specifications required to develop an effective and functional prototype. The design provides a clear concept of how the system will operate and serves as a guide for the development team.

Prototyping. In the prototyping phase, the system is constructed and refined. A well-defined prototype is created, tested, and evaluated to ensure it meets the intended objectives. This prototype serves as a reference for future system improvements and provides a practical demonstration of the machine's functionality.

Customer evaluation. The customer evaluation phase assesses the satisfaction and usability of the prototype among potential users. Feedback from users helps the researchers understand the system's benefits and

identify areas for improvement. This phase also provides insights for future studies and encourages innovation in similar systems.

Review and evaluation. During this phase, the system undergoes a final review and evaluation. Researchers assess the system's overall performance, functionality, and reliability. The results of this evaluation are used to compile all gathered information and inform any necessary adjustments before the final development stage.

Development. The development phase involves building a fully functional system based on the refined prototype. The researchers focus on ensuring that the vending machine operates efficiently and demonstrates improved performance compared to the initial prototype. This phase represents the tangible realization of the system's design and functionality.

Testing. In the testing phase, the Bottle Reclassification Vending Machine is thoroughly examined to ensure it operates correctly. Researchers identify potential errors, monitor system performance, and implement corrective actions to prevent issues. This phase guarantees that the system functions reliably and meets quality standards before release.

Release. The release phase marks the deployment of the finalized system. The machine is made available for practical use, demonstrating its benefits and performance to end-users. This phase ensures that the system can be implemented effectively and contributes to environmental sustainability and agricultural support through proper plastic bottle reclassification and seed distribution.

Technical Framework

The development of the product requires the integration of data, hardware, and software components. Each component plays a critical role

in the overall functionality of the system.

Materials

Hardware includes all physical devices and equipment necessary to run the system, such as sensors, microcontrollers, and actuators, which enable the system to interact with the environment and execute tasks. Software encompasses the programs, algorithms, and interfaces that control the hardware, process data, and facilitate user interactions. Together, these components work in harmony to ensure the system performs its intended functions effectively and efficiently.

Software

Table 2 shows the software used in creating this project.

Table 2

Software requirement

Software	Specification
Arduino IDE	Arduino-ide_2.0.2_Windows_64bit
	Size 157 MB (165,608.048 bytes)

The project requires specific software materials to operate the machine effectively. These software components work in conjunction with the hardware to ensure the system performs all its intended tasks. Central to the system are the programming codes, which execute the specific operations necessary for the machine to function correctly. These codes coordinate the hardware components, process the input data, and manage the overall workflow, making them essential for the accurate and reliable operation of the vending machine.

Hardware

Table 3 shows the hardware used in creating this project.

Table 3

Hardware requirements

Parts	Function	Specification
Arduino Mega 2560	It serves the brain of the projects.	5 Volts
IR Break Sensor Beam	A Sensor that detects if its plastic bottle	5 Volts
Servo Motor	It serves the door of the machine if it is accepted or not	5 Volts
Solar Panel and Rechargeable Battery	A electric device that makes the whole machine works.	Battery : 12V 20H Solar Panel : 50Watts 12V
LM2596	A component that gives the other devices 5 volts instead of 12 volts	12 volts
LCD	It display what the machine detects and the total points	5 Volts
Micro Push Button	A button that triggers the stepper motor to dispense a seed with the right number of points	5 Volts
Stepper Motor	This device rotates to get their reward when the push button is pressed	5 Volts
Loadcell	A device this measure the weight of the plastic bottle	5 Volts

Parts	Function	Specification
Ultrasonic Sensor	A sensor that detects when a plastic bottle can place inside the PVC	5 volts

Table 2 lists the hardware materials required for the development of the bottle reclassification vending machine. Among these, the ultrasonic sensor is particularly essential, as it plays a critical role in ensuring the system performs accurately. The sensor detects the presence and placement of plastic bottles, allowing the vending machine to store them correctly and operate efficiently.

In addition to the ultrasonic sensor, other hardware components are also necessary to enhance the system's functionality and reliability. These materials work together to support the mechanical operations, data processing, and overall performance of the vending machine, ensuring that it meets the intended objectives of bottle reclassification and seed distribution.

System Design

Figure 2 illustrates the main 3D prototype of the study. The prototype measures 4 units in height and 5 units in width. The machine is powered either by a solar panel or a battery, which is placed on the top of the unit. The vending machine features six buttons corresponding to six different seed options, six springs for dispensing the seeds, and a pipe where users insert plastic bottles for reclassification. This design ensures that the system is functional, user-friendly, and capable of performing its intended tasks efficiently.

Figure 2

The main prototype
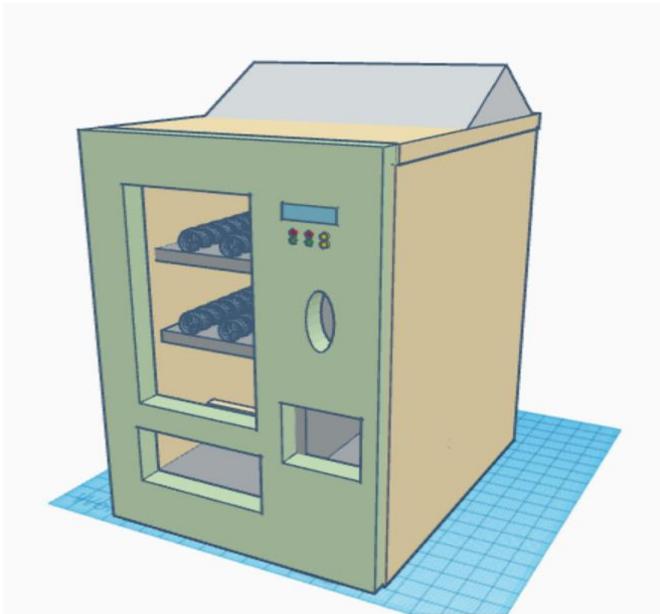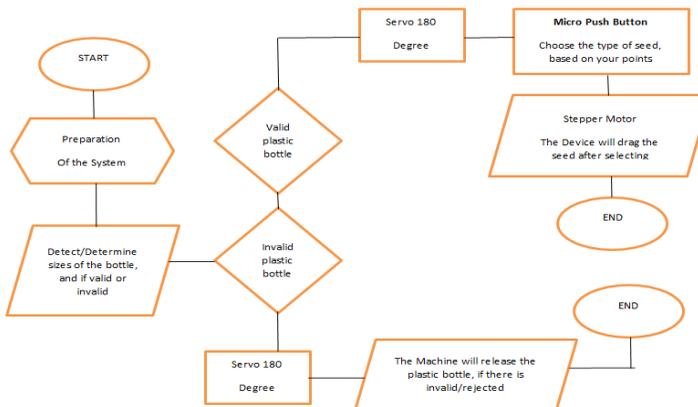

Figure 3

Project system flow

Figure 3 illustrates the system flow of the bottle reclassification vending machine, demonstrating how the system operates. Initially, users insert small, medium, or large plastic bottles into the machine. The sensor then evaluates each bottle to determine whether it meets the required

specifications. Bottles that are severely damaged, misshapen, filled with liquid, or too heavy are rejected and not accepted by the machine.

Plastic bottles that are intact, empty, and within acceptable size limits are accepted and processed. Once the bottle is validated, the user can select their preferred seed by pressing the corresponding seed button. After the selection is made, the machine dispenses the chosen seeds, completing the transaction. This flow ensures that only suitable bottles are collected while providing users with a seamless and rewarding experience.

Figure 4
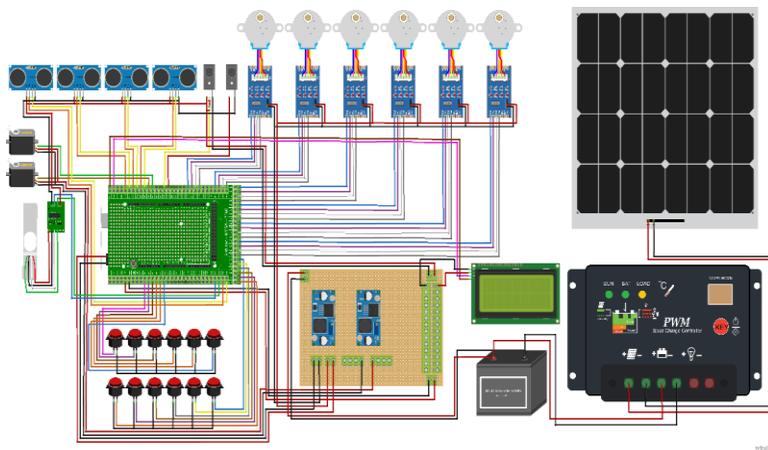
Detailed circuit diagram

Figure 4 illustrates the overall circuit layout and the system flow of the bottle reclassification vending machine. This layout enables users to fully control and operate the system. The machine incorporates four sensors, servo motors, an Arduino Mega 2560, stepper motors, and other essential components. The sensors play a critical role in detecting the size and presence of plastic bottles, while the other components support various movements and operations required for the system to function efficiently. This integrated circuit design ensures coordinated performance across all

parts of the vending machine.

Figure 5

LCD Display shows the accumulated points for plastic bottles

Figure 5 illustrates how the system calculates and displays points for each plastic bottle deposited, with different bottles corresponding to varying point values. The accumulated points are shown on an LCD screen, allowing users to track the total points they have earned by recycling plastic bottles through the machine. This feature provides immediate feedback and encourages user engagement in responsible recycling practices.

Figure 6 illustrates a prompt indicating that the machine is dispensing a pack of seeds selected by the user using the points they have accumulated. Users can choose their preferred seed pack by pressing the corresponding buttons, with each button linked to a different type of seed. This feature allows users to redeem their points easily while selecting the seeds they desire, making the system interactive and user-friendly.

Figure 6

Machine dispensing pack of seeds

Figure 7

Machine displays the size of the plastic bottle

Figure 7 demonstrates that the machine is capable of reclassifying plastic bottles based on their size, ensuring that the points awarded to users correspond accurately to the type of bottle deposited. The system uses ultrasonic sensors to measure the height of each inserted bottle, allowing the machine to distinguish between small, medium, and large bottles. This precise classification ensures fairness in the points system and enhances the accuracy and reliability of the vending machine.

Figure 8

Development system

Figure 8 illustrates the operational process of the system. The user begins by inserting a plastic bottle into the PVC pipe. Once the bottle is dropped, the ultrasonic sensor detects its size and determines the corresponding number of points. The accumulated points are then displayed on the LCD screen. After viewing their available points, the user can press the designated push button to dispense a seed pack of their choice as a reward. This process demonstrates the system's efficiency in integrating bottle classification, point calculation, and seed dispensing into a single automated workflow.

Testing

The study employed system testing to assess the efficiency and functionality of the vending machine. Performance results were evaluated

after the system completed its operations to confirm and validate its processes. Manual testing was used to examine each feature and ensure that all components operate correctly. This approach allowed the researchers to identify errors, verify quality, and make necessary adjustments. Testing each system component individually ensures that all parts work together harmoniously, while the analysis of error data provides insights for system improvement and more efficient future testing.

The initial step in testing was to ensure proper system operation in line with the design specifications. Simulated system operations were conducted to validate the workflow and functionality. System requirements were also reviewed during this phase to ensure that all criteria were met. The final step involved output validation, confirming that the proposed system performs its intended functions accurately and efficiently.

System Evaluation and Testing

This section presents the overall results of the survey conducted with 30 respondents. The questionnaire was designed to evaluate three key aspects of the system: functionality, environmental impact, and profitability. Responses were measured using a Four-Point Likert Scale, with the options: strongly agree, agree, disagree, and strongly disagree.

Table 9

Weighted mean distribution of the criteria for the developed system

Criteria	Weighted Mean	Remarks
Functionality	3.44	Strongly Agree
Environmental	3.58	Strongly Agree
Profitable	3.41	Strongly Agree
Average	**3.47**	**Strongly Agree**

The overall evaluation of the system shows an average weighted mean of 3.47, indicating that respondents rated the Bottle Reclassification Vending Machine positively across the assessed aspects: functionality, environmental impact, and profitability. This suggests that the system is capable of performing the tasks it was designed for efficiently.

In terms of functionality, the program installed on the hardware operates correctly and is user-friendly. Respondents reported ease of use when interacting with the hardware, resulting in a Strongly Agree rating for functionality with 3.44.

Regarding the environmental impact, the system was rated positively for its contribution to sustainable practices. The average weighted mean for environmental performance is 3.58, with respondents strongly agreeing that the machine promotes eco-friendly behavior.

For profitability, the system was also evaluated as effective in helping users save money by providing seeds in exchange for recycled plastic bottles. The average weighted mean in this category is 3.41, with respondents giving a Strongly Agree remark, indicating that the system provides economic benefits in addition to its environmental and functional contributions.

Economic feasibility. Economic feasibility evaluates whether the anticipated benefits of the system outweigh the project costs. A cost-benefit analysis was performed to assess the value of the system, considering both its advantages and disadvantages. The analysis also provided feedback on the potential impact of the system on its users, demonstrating that the proposed vending machine can offer practical benefits while remaining economically viable.

Technological feasibility. The project demonstrates technological feasibility through its successful implementation. Users provided positive

feedback regarding the system's design and functionality, including suggestions such as improving the machine's appearance and tagline for greater attractiveness. Overall, the system's goal of providing points for recycled bottles in exchange for seeds was well-received by users, showing that the technology meets its intended purpose.

Operational feasibility. The developed system is operationally feasible because it is designed to be user-friendly and easy to understand. Survey results indicate high user satisfaction, and the inclusion of a procedural video further aids in guiding users through the machine's operation. The system's simplicity and clarity make it accessible for various users, including farmers, gardeners, and community residents.

Conclusion

The Arduino-based bottle reclassification vending machine successfully addressed both environmental and agricultural needs by providing a system that converts plastic bottles into points redeemable for seeds. The machine accurately detects and classifies bottles of different sizes using ultrasonic sensors, ensuring that each bottle corresponds to the appropriate points and seed type. The prototype demonstrated functionality, user-friendliness, and operational efficiency, earning positive feedback from respondents in terms of functionality, environmental impact, and profitability. By incentivizing recycling and promoting the use of seeds for planting, the system not only encourages sustainable practices but also supports agricultural productivity for farmers, gardeners, and community residents. This innovative project highlights the potential of technology to contribute meaningfully to environmental preservation and community development.

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