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INNOVATION THROUGH SOLID WASTE MANAGEMENT AND RECONSTRUCTION: A UNIVERSITY EXPERIENCE

INOVAÇÃO ATRAVÉS DA GESTÃO DE RESÍDUOS SÓLIDOS E DA RECONSTRUÇÃO: UMA EXPERIÊNCIA UNIVERSITÁRIA

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Abstract
The manuscript describes the experience of university students enrolled in the Sustainable Development course, part of the academic programme of a higher education institution, as they develop a project to address the environmental sustainability problem of solid waste. The methodology implemented to achieve the proposed goal consisted of Project-Based Learning (PBL), through which a Technology Project (Tech. Proj.) adapted to first-year students was developed. This pedagogical approach aimed to promote innovation in the design and construction of devices that support the efficient management of solid waste. By way of illustration, a project carried out by a group of students is added. In general, the response from the young people was positive, resulting in a favourable outcome, as the students demonstrated a high degree of commitment by proposing to transform innovative ideas into practical solutions that contribute to caring for the environment and the well-being of society.

Resumo
O manuscrito descreve a experiência de estudantes universitários matriculados na disciplina de Desenvolvimento Sustentável, parte do programa acadêmico de uma instituição de ensino superior, no desenvolvimento de um projeto para abordar o problema da sustentabilidade ambiental relacionado aos resíduos sólidos. A metodologia implementada para atingir o objetivo proposto consistiu na Aprendizagem Baseada em Projetos (ABP), por meio da qual foi desenvolvido um Projeto Tecnológico (Proj. Tecn.) adaptado a alunos do primeiro ano. Essa abordagem pedagógica visou promover a inovação no projeto e na construção de dispositivos que auxiliem na gestão eficiente de resíduos sólidos. A título de ilustração, apresenta-se um projeto realizado por um grupo de estudantes. De modo geral, a resposta dos jovens foi positiva, resultando em um desfecho favorável, visto que os estudantes demonstraram um alto grau de comprometimento ao proporem a transformação de ideias inovadoras em soluções

Keywords: Experiential Learning, Innovation, Reconstruction, Solid Waste Managment.

práticas que contribuam para o cuidado com o meio ambiente e o bem-estar da sociedade.

Palavras-chave: *Aprendizagem Experiencial. Inovação. Reconstrução. Gestão de Resíduos Sólidos.*

1 INTRODUCTION

Caring for the environment is, today, a matter of extreme urgency. The planet is at a point of no return; despite international agreements, solid waste generation continues to rise alongside population growth. According to projections by the United Nations (UN), various international organisations, researchers, and ecosystem advocacy groups, by 2050, there will be so much solid waste that it will seriously impact the living environment of all species on the planet.

Therefore, it is not enough to raise social awareness about the care, protection and preservation of the environment; rather, it is necessary to give it priority by establishing educational programmes (at all levels), accompanied by concrete actions that address this problem. Thus, universities have incorporated subjects that fulfil this purpose; although in many cases they do not receive the importance they deserve, they are nonetheless significant.

Within this framework of ideas, the manuscript aims to publicize the actions derived from the Sustainable Development course taken by Mechatronics students at a Higher Education Institution (HEI) in southern Tamaulipas, Mexico, during the first semester, which includes the development of projects with a social impact. As a result, the students were inspired to create and design objects/artifacts from solid waste, reconstructing them to give them a second life and caring for the environment. The above is explained in detail below.

2 THEORETICAL FRAMEWORK

2.1 Background

Various studies have examined the importance of solid waste management (SWM) in HEIs. Thus, the work carried out by Urure *et al*. (2024) to evaluate the level of knowledge and practices related to solid waste management among university students in a Peruvian region employed a non-experimental, quantitative, correlational, and prospective design, selecting a sample of 228 students.

In collecting data, the authors implemented two nationally validated questionnaires using Cronbach's Alpha, obtaining a reliability of 0.823 for the evaluation of practice, and the Kuder-Richardson formula, yielding a reliability of 0.755 for the evaluation of knowledge. The results showed a predominance of the 20-24 age group (86%) and females (89%). Regarding knowledge of SWM, the results were mixed. On the one hand, the percentage of correct answers (62.3%) indicated an average level of understanding; on the other hand, the question with the highest percentage corresponded to the recovery of solid waste ($\bar{X}$ = 0.92; SD 0.25). In contrast, the question with the lowest percentage of correct answers concerned solid waste generation. Regarding waste management practices, 71.5% were carried out satisfactorily. Therefore, a higher level of knowledge leads to better SWM practices.

In another documentary-based study, based on research in the National Registry of Higher Education Options (RENOES) and through data analysis using the R programming language (R Core Team, 2023), was carried out at the University of Veracruz. Mexico—Olivo *et al*. (2024) considered that the lack of inclusion of subjects related to GRS in national higher education programmes results in a marked deficit in addressing this problem, making its incorporation into academic curricula crucial. In addition, they noted a strong tendency to offer such subjects as electives, rather than integrating them as compulsory components within the educational framework, particularly in postgraduate studies. The authors therefore propose updating and expanding the range of university educational programmes related to the national problem of solid waste, thus training professionals and researchers with the capacity to face the challenges ahead.

The thesis by Girone *et al*. (2024) examined the implementation of solid waste management strategies through the circular economy in the municipality of Ulcumayo, Peru. The researchers implemented a mixed-methods, descriptive, cross-sectional design, collecting data through observation guides, questionnaires, and interviews to analyse the current state of waste management in the community—the study sample was selected from a population subgroup within the district of Ulcumayo. The findings revealed a significant deficit in knowledge of the circular economy and solid waste management.

On the other hand, participants expressed a high degree of acceptance and willingness to adopt initiatives related to the circular economy and proper solid waste management. Therefore, the research highlighted the importance of implementing sustainable strategies that promote socioeconomic development and improve environmental quality.

2.2 Economic development and solid waste generation

Population growth and industrial development have led to a significant increase in waste generation, which has given rise to a series of environmental and public health problems, such as the proliferation of harmful fauna and the contamination of water, soil and air. This is because urban development and population growth create a strong demand for resources, which is met through the excessive use of natural resources, leading to their depletion due to overexploitation and an increase in waste generation, two of the most pressing environmental problems of the 21st century (Ortíz, 2025).

Regarding the issue raised here, Urure *et al*. (2024) emphasise the inefficient management of solid waste as one of the main environmental and public health challenges associated with urbanisation, which, in turn, leads to increased waste generation. In response, international organisations such as the World Health Organisation (WHO) and the World Bank (WB) have highlighted that a significant proportion of waste is inadequately managed, posing a threat to the environment and human health.

A clear reflection of the situation described above is the Latin American context, which has become a significant focus of attention due to the high volume of waste produced daily, the increase in informal dumps, the burning of waste, and its disposal in open-air landfills, as well as poor practices linked to inadequate waste management (UN, 2026). In Mexico, the Bordo Poniente, the capital city's largest landfill, was closed in 2011, with an estimated 70 million tonnes of waste buried there. It is therefore essential to seek innovative solutions to reduce, dispose of, and utilise solid waste within a circular economy that safeguards the natural environment (UN, 2018).

2.3 Sustainability and the circular economy

On the other hand, in relation to waste management and sustainability, Rivera *et al*. (2024) establish that the circular economy presents an opportunity that is currently gaining importance as a new economic model, which allows for the valuation of human heritage by not returning to nature to take what is necessary for production, but rather taking waste to rebuild products and optimise their helpful life.

Therefore, the circular economy emerges as an alternative to the linear model of production and consumption, characterised by the following processes: take, make, use, and dispose. This paradigm has, as already mentioned, led to the overexploitation of natural resources and the accelerated generation of waste, negatively affecting the planet's sustainability.

Furthermore, it is linked to the proposal for the reconstruction of solid waste based on three functions to be assessed: recognising that natural resources are finite, and therefore their extraction must be used in a relevant and rational manner; assimilating waste, unlike linear economy production and consumption patterns; finally, recognising that this new type of economy is also the basis of utility linked to the satisfaction of fundamental human needs, improving the quality of life of communities and their environment (Díaz and Escárcega, 2009).

In summary, the circular economy is built on a foundation of the production system approach, through strategies such as reducing, reusing, recycling, restoring, redesigning, renovating, and remanufacturing, to extend the useful life of materials. This perspective favours the reconstruction of objects, extending their usefulness for as long as possible, transforming waste into new resources, and reducing pressure on the natural environment (Valero *et al.*, 2025). As a result, waste is minimised, ecosystems are regenerated, and economic resilience, sustainability and environmental preservation can be significantly enhanced.

2.4 University social responsibility

The subject matter addressed here is based on and aims to bring together both knowledge and practices that enable students to apply SRM, directly related to their professional training and ethical performance, assuming both environmental awareness and the experience of University Social Responsibility (USR), transforming their worldview and becoming strategic agents of social change.

Therefore, it is a priority for students to consider their individual or collective contributions to caring for the environment as conscious decisions, with the intention of meeting the environment's priority needs. However, to achieve this, it is imperative to promote the professional and research training of teachers and students, to develop specialised skills to produce efficient solutions that facilitate the care and preservation of the living environment.

This will be possible as long as universities develop academic programmes with subjects that align with proper SRM (Olivo *et al*., 2024). This is reinforced by the significant percentage of students who do not sort waste appropriately or reuse it, and, if anything, engage in a few sustainable practices or campaigns that involve waste management in an operational manner rather than as a conscious commitment to promoting environmental care (Moreira, 2025). For this reason, it is essential to strengthen three dimensions: knowledge, procedures, and practices for managing solid waste, and a collaborative, creative, and innovative attitude among students.

3 METHODOLOGY

Taking advantage of the Sustainable Development course and considering the gamification of solid waste use, the students decided to reuse it to design and build a device that would meet a specific need of people living in vulnerable conditions. To do this, they had to develop a work plan that they put into writing in a manuscript with the following structure: proposal of ideas, selection and description of the selected idea, socio-environmental issues, justification, objectives, need it solves, description of the construction process, results (involving the Sustainable Development Goals), conclusion (learning experience), references. Similarly, the device was presented following the Project-Based Learning (PBL) methodological approach (Heydrich *et al*., 2025; Medina *et al*., 2025) and some aspects of the design of a Technological Project (Pérez, 2021). This encouraged both creativity and innovative spirit among new university students and allowed them to showcase what they had learned in secondary school, as well as their acquired skills in design, construction, and programming.

Construction process

The construction of the device had to follow a specific procedure requiring several aspects:

1. Sketch/diagram: drawing made with a programme (MatLab, Solidworks, LabVIEW, etc.), with the aim of showing a preliminary design to guide the

construction of the device.

2. Collection of solid waste materials: selecting and collecting those that were in optimal condition to meet the objective, with evidence of this action being provided.
3. Sanitisation of these materials: cleaning and drying of solid waste before handling, to avoid damage to health, showing evidence corresponding to this part of the process.
4. Construction: integration of all the elements necessary for the formation of the device/artifact, requiring sub-phases to perform functionality tests, until the project is completed, showing evidence of the process.
5. Presentation of the device/artifact: its functionality and operability.
6. Delivery of the manuscript: after step five, deliver the final document or project in accordance with the previously stipulated characteristics, both in terms of normative use of language and characteristics of academic text in APA seventh edition format.

4 RESULTS AND DISCUSSION

One of the artefacts constructed by students is presented, with their explanations added in italics:

4.1 Project name

Wall-E rubbish collector, made from waste cardboard, which is biodegradable and has a high recycling rate, with low production costs.

4.2 Authors

First-semester students in the Mechatronics programme.
Montoya García Miranda Yoselin.
Cervantes Pérez Luis Jesús.
Regalado Calles Pedro.

4.3 Issues

According to Inemesit U (2024), ‘the production and disposal of cardboard worldwide has significant environmental implications. On the positive side, cardboard is biodegradable and recyclable, with a 92.9% recycling rate. However, cardboard production comes with ecological costs (p. 4).

The problem of plastic has become very serious. Buteler (2019):

> *Global plastic production exceeds 380 million tonnes per year, and three-quarters of this volume is discarded as waste, which not only affects the aquatic environment through species loss and eutrophication, but also terrestrial ecosystems (p. 6).*

Municipalities in the south of the state, such as Tampico, Ciudad Madero, and Altamira, had the highest levels of untreated solid waste, “due to persistent deficiencies in recycling infrastructure and the lack of an effective policy for separating waste at source. Therefore, we can see that such waste is indeed polluting” (p.5).

4.5 Objective

To design and build a Wall-E cart made from recycled materials such as cardboard and plastic bottles, so that it can collect rubbish practically and creatively.

4.6 Justification

Institutional:

This project is possible because the university's mission is to train professionals committed to sustainable development, technological innovation, and social responsibility, and to support initiatives that combat pollution.

Academic:

The Sustainable Development course involves developing a practical project that combines technology and sustainability. This project allows students to apply their knowledge of electronics and design to address pollution.

Social:

The aim is to raise awareness of environmental pollution, motivate the community to keep public spaces clean, and encourage the reuse of solid waste to benefit vulnerable areas.

4.7 Need addressed

The journalism website Nota Tamaulipas (2025) mentions that:

> Without any agency having accurate data or specific studies, plastic pollution has become a structural problem on the coast of Tamaulipas, where tonnes of waste such as bottles, bags, and disposable packaging have accumulated on beaches, estuaries, and bodies of water, directly affecting marine life and the ecological balance (p.2).

For the team, the project called Wall-E, made from cardboard and recycled bottles to collect rubbish, seeks to solve both environmental and educational problems. This initiative reuses materials that would normally pollute the environment, promoting recycling and ecological awareness. In addition, it encourages innovation by offering a practical way to keep spaces clean, fosters creativity and technological skills among team members, and represents an economical and sustainable alternative for caring for the environment.

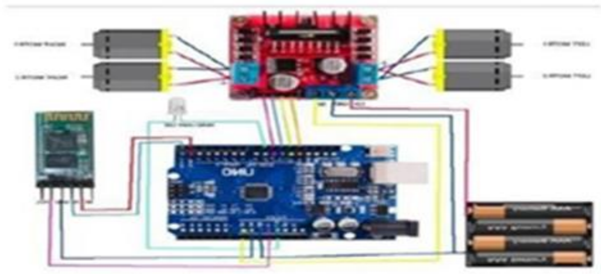
4.8 Production process

The project began with the planning phase, in which the materials to be used and the nature of the work to be carried out were determined. As a result, it was decided to create a remote-controlled robot for collecting cardboard and plastic waste.

To this end, a visit was made to a recycling plant in the port to obtain the necessary material (cardboard), and polyethylene terephthalate (PET) plastic bottles were also collected for use in the construction of the device. These were cleaned and disinfected (as they had been found in rubbish bins or on the ground), dried and cut, i.e., recycled and rebuilt, after having been previously used to contain various types of liquids.

Figure 1

Connection diagram.



Source: Crazy Think (2020).

The circuit was designed to ensure the robot's mechanical and electrical functionality. To this end, recycled components from previous projects were used, including Arduinos, protoboards, resistors, and other components. Priority was given to the reuse of elements to avoid incorporating new components, in line with the SWM.

Figure 2

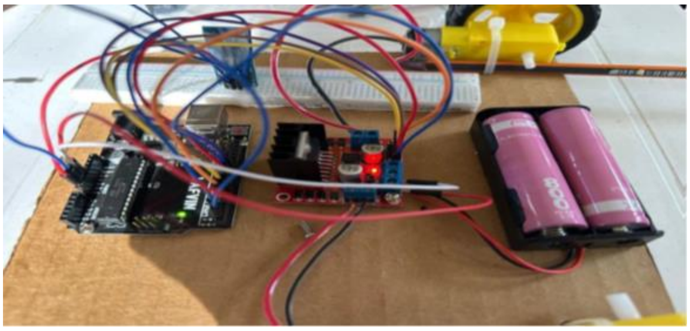
Construction of the structure.

Source: own elaboration (Montoya, Cervantes and Regalado, 2025).

The robot's structure was made out of cardboard, inspired by the character Wall-E. It was assembled by cutting recycled cardboard boxes with scissors and rulers for measuring, and using craft knives to shape the main body, eyes, arms, and collection system. All the pieces were joined together with silicone, and aesthetic details were added. In addition, two collection devices were built: one for cardboard and another made from recycled plastic.

Figure 3

Connections.

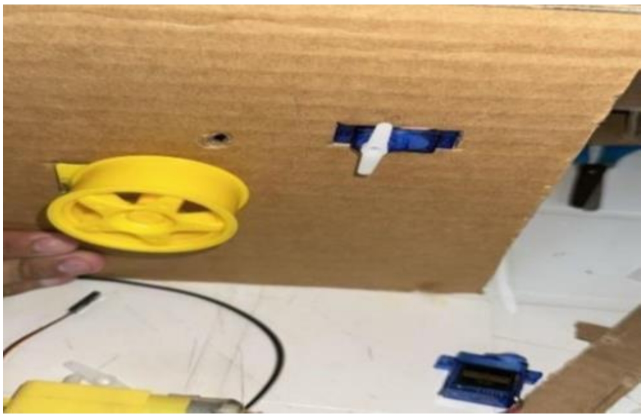


Source: own elaboration (Montoya, Cervantes and Regalado, 2025).

Servomotors connected to a Bluetooth board controlled the arms and head, enabling remote operation. Cardboard sheets were cut to form the collector's base, with cut bottles attached to a plastic shaft powered by a motor that rotated the plastic fibres to facilitate waste collection.

Figure 4

Assembly of components.



Source: own elaboration (Montoya, Cervantes and Regalado, 2025).

Once the robot had been constructed, paint was applied to add the finishing touches. Finally, various tests were conducted to identify potential faults and ensure the prototype was functioning correctly.

5 RESULTS AND DISCUSSION

5.1 Results

Firstly, the device developed and in operation is presented, in accordance with what the students proposed in their project, fulfilling the objectives established to achieve the intended goal, and its presentation at a local, regional, or national conference.

Figure 5

BLIP is completed and in operation.

Source: own elaboration (Montoya, Cervantes and Regalado, 2025).

Figure 6

Project exhibition.

Source: own elaboration (Montoya, Cervantes and Regalado, 2025).

5.1 Student learning experience

After conducting multiple tests and holding various meetings, the project goal was achieved: to develop a remote-controlled robot for waste collection made entirely from reused materials. However, some changes were made to the initial idea, and electronic and mechanical components were incorporated to improve the prototype's overall mobility. For example, the wheels were redesigned to give it a look more similar to the character WALL·E, resulting in a more realistic and attractive appearance.

In addition, the model's main structure, or box, was rebuilt to optimise its presentation and visual finish. Finally, a voice recording module was added, allowing the prototype to emit sounds characteristic of the character, increasing its interactivity and realism.

This achieved the established objective, as the robot demonstrated exemplary performance and clear electrical and mechanical functioning, moving forward remotely via Bluetooth and collecting rubbish or small debris efficiently.

he project is aligned with the following Sustainable Development Goals (SDGs) of the 2030 Agenda:

SDG 3: Good health and well-being, by contributing to the reduction of pollution and improving the quality of life in communities.

SDG 9: Industry, innovation and infrastructure, by promoting the creation of sustainable technological solutions.

SDG 11: Sustainable cities and communities, by promoting cleaner and more orderly urban environments.

SDG 12: Responsible consumption and production, through the reuse and recycling of materials.

SDG 13: Climate action, by promoting initiatives that reduce environmental impact and promote ecological awareness.

5.2 Discussion

In the words of Moreira *et al*. (2025), today, few students reuse solid materials (such as paper, packaging, and textiles) due to the limited adoption of circular economy strategies in the university context. This situation is exacerbated by the lack of awareness-raising initiatives, and those that do emerge are poorly promoted. So, SWM among peers is minimal, and only a few teachers organise activities to sort and manage these materials. Therefore, "there is a lack of an educational and participatory component that promotes sustainable behaviours" (p. 285) that contribute to solving the central problem of environmental pollution.

In this regard, it should be noted that the incorporation of compulsory subjects on environmental care into the curricula of Mexican universities raises practical awareness, as well as ethical and professional awareness among young people, by promoting actions that benefit society and the natural environment through SWM (Pell and García, 2025).

However, globally, universities that excel in waste management are located in countries with high Human Development Index (HDI) scores, which maintain an optimal relationship between economic development and comprehensive waste management (Vilchis *et al*., 2025). In this regard, there is a discrepancy in the positioning of Mexican higher education institutions in the international rankings of developed countries. This is reinforced by Pedroza (2022), who states that in the field of sustainability, the economic development of such nations is a relevant factor in the sociocultural context, exerting a significant influence on the efficiency of SWM practices.

On the other hand, proper management of natural resources and waste management, such as recycling and reuse, together with the application of technology (Di Foggia and Beccarello, 2021), can generate various types of social benefits, such as the creation of renewable energy sources for public lighting, the creation of dishes made from fruit and vegetable peels by postgraduate students at the National Polytechnic Institute (IPN) (La Jornada, 2025); edible packaging made from agricultural by-products (Ferreira *et al*., 2025); and many other things.

Thus, the relationship between the circular economy and the environment, within the current economic model, must encompass "three functions: resource provider, waste assimilator, and source of utility" (Ramírez *et al*., p. 211) in line with the Ecverde report (2021), which establishes the urgent need for solid products discarded as waste to be designed in such a way that they can be rebuilt, to reincorporate them as raw materials or as tools that are useful to people, particularly those living in vulnerable conditions.

Finally, the redesign of solid waste is a catalyst for cognitive and emotional processes among teachers and students, through meticulous planning, the use of pedagogical tools, and, notably, the integration of new specialised teaching methods. This approach is based on promoting comprehensive knowledge that fosters sustainability (Pavón *et al*., p. 96).

6 CONCLUSIONS

Solid waste management faces significant challenges, including the exponential increase in waste generation, limited landfill capacity, and negative environmental impacts. However, it is essential to note that one alternative that can mitigate this effect is education, which is an ideal vehicle for combating such a severe problem through awareness-raising, waste management, and the reuse/reconstruction of waste, mediated by the creativity and innovation of university students.

In this context, sustainable development can be understood and interpreted from a curricular perspective, whereby university study plans and programmes (in different areas of knowledge) achieve a point of convergence whereby students become agents of social change, producing graduates who are aware of their environment and sensitive to its needs, applying the knowledge they have acquired to shape their lives and work.

The importance of the circular economy for the use of solid waste, which provides economic and social benefits, specifically for vulnerable communities, is evident. It is therefore a question of going beyond the classroom with the intention of making the results of the applicability of knowledge accessible, by solving the vital needs of disadvantaged communities, while at the same time generating a metacognitive, practical-professional process that brings theory down to earth in concrete human reality.

Therefore, it is essential to promote activities that foster creativity in students, encouraging the incubation and generation of ideas that contribute to transforming the current ecological and social environments of economically disadvantaged communities. The project developed by the students highlights the importance of the topic, as the proposal helps to address one of the ecological problems currently affecting living beings through GRS; however, apathy towards this reality will have far-reaching adverse effects on the sustainability of the planet.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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