Circular Innovation in Technical Education: A Design Thinking-Based Pedagogical Practice Using Reused Materials

Clariane Teixeira Pessoa Mamona[1*], Pietro Carlos Gonçalves Conceição[2]
[1,2] University Senai Cimatec, *NEPE, Salvador, Bahia, Brasil*
**Corresponding author: University Senai Cimatec; NEPE; clariane.pessoa@fieb.org.br*

Abstract: This paper presents a pedagogical practice developed with technical education students, aiming to foster sustainability, creativity, and social engagement through the reuse of disposable materials in the construction of functional objects. The activity was structured around the five stages of Design Thinking, providing students with an active, problem-centered learning experience. Throughout the process, students transformed solid waste—such as PET bottles and cardboard—into toys and utensils, combining technical knowledge, ecological awareness, and innovation. The project culminated in an exhibition open to the institution's internal public, during which students showcased their prototypes and explained their creative solutions. Simultaneously, a solidarity initiative was promoted through the collection of non-perishable food items for donation to a local charity. The results indicate that the adopted approach significantly contributed to the development of socio-environmental competencies and to the advancement of the Sustainable Development Goals, highlighting the potential of interdisciplinary pedagogical strategies in strengthening both technical and civic education. The experience proved to be low-cost, replicable, and highly effective in integrating theory, practice, and social responsibility.
Keywords: Pedagogy. Recycling. Sustainability. Innovation. Prototypingæ.

1. INTRODUCTION

The global environmental crisis, intensified by rampant consumption and improper disposal of solid waste, has heightened the demand for educational practices that promote sustainability and circular economy principles. In this context, education plays a strategic role in forming critical and conscious citizens capable of proposing innovative solutions to contemporary socio-environmental challenges [1][2].

Among the most promising strategies is the use of disposable materials in practical and creative pedagogical activities. Transforming solid waste into functional objects—such as toys, artworks, or technological devices—not only reduces environmental impact but also fosters creativity, autonomy, and critical thinking [3][4]. Such practices have been successfully integrated across educational levels, from basic to technical and higher education, promoting both material reuse and meaningful learning. Studies indicate that recycling workshops—including those reusing 3D printing waste—develop technical and entrepreneurial skills while engaging students in circular economy logic [5]. In design and engineering, active methodologies such as Industry 4.0 technologies demonstrate the potential of Education for Sustainable Development (ESD) to change behaviors [6]. Furthermore, educational experiences focused on upcycling and green prototyping positively impact students' environmental attitudes, strengthening ecological awareness and social engagement [7]. Integrating sustainable practices into technical curricula enables students to act as transformative agents, connecting theory and practice through projects that combine creativity, socio-environmental responsibility, and innovation [8]. The Design Thinking methodology, a human-centered and

iterative approach, offers a structured framework for tackling such complex problems. By following its stages—empathize, define, ideate, prototype, and test—students engage in a hands-on process that fosters empathy, collaboration, and innovative solution development [9]

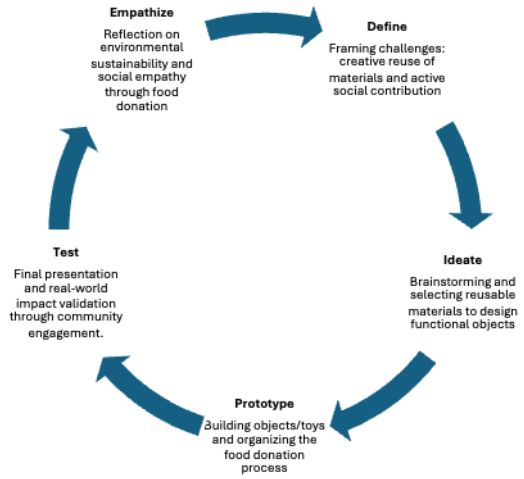
This paper presents a pedagogical practice developed with technical education students, structured around the Design Thinking framework. The objective of this work was to promote sustainability, creativity, and social engagement through the transformation of disposable materials like PET bottles into functional objects. This approach encouraged ecological awareness, innovative thinking, and active learning. Aligned with circular economy principles and the Sustainable Development Goals (SDGs), the proposal integrated education, innovation, and social responsibility into a practical and meaningful experience.

2. METHODOLOGY

The methodology of this study was based on the principles of Design Thinking, a human-centered approach that encourages creative problem-solving through an iterative and collaborative process [9].

The proposed activity involved the construction of functional objects or toys from disposable materials (with emphasis on plastics, such as PET bottles), combined with a solidarity initiative to collect non-perishable food items. The activity was structured around the five stages of Design Thinking: Empathize, Define, Ideate, Prototype, and Test, as illustrated in Figure 1.

Figura 1 - Design Thinking stages applied to the pedagogical practice.



Stage 1 – Empathize

The initial stage aimed to raise student awareness across two complementary dimensions:

- Environmental awareness: By proposing the reuse of disposable materials, students were encouraged to reflect on the environmental impact of consumption and waste, as well as on the principles of the circular economy.
- Social solidarity: The voluntary donation of one kilogram of non-perishable food fostered empathy with vulnerable communities, encouraging civic engagement and collective responsibility.

Stage 2 – Define

Based on the initial reflections, two core challenges were defined:

- Ecological challenge: "How can we transform waste into functional objects or creative toys, adding value and extending their life cycle?"
- Social challenge: "How can we contribute to a charity institution through the collection and donation of food?"

These challenges guided the following stages, even if not explicitly framed as formal problem statements.

Stage 3 – Ideate

At this stage, students were invited to freely explore ideas based on the materials available:

- They conducted brainstorming sessions on transformation possibilities, considering functional, aesthetic, and social aspects.
- They generated multiple design alternatives and selected the most feasible idea for implementation.
- Creative freedom was essential to stimulate divergent thinking and innovation.

Stage 4 – Prototype

Prototyping was carried out through:

- The physical construction of the objects/toys, applying manual skills and basic techniques for assembling, cutting, and adapting reused materials.
- The organization of the food donations, also treated as a symbolic prototype of a concrete act of solidarity.

During this stage, students encountered and solved real execution challenges, such as ensuring structural stability and adapting shapes.

Stage 5 – Test

Finally, the validation of the prototypes occurred through practical activities:

- In-class presentations, during which peers and the instructor assessed creativity, functionality, and aesthetics.
- Real use of the toys, which were donated to children in a charity institution—serving as a field test in an authentic context.
- Delivery of food donations, completing the social impact cycle and reinforcing the collective value of the actions developed.

3. RESULTS AND DISCUSSION

The culmination of the project took place through an interactive exhibition of the toys and functional objects created by students using reusable materials such as PET bottles, cardboard, plastic caps, and fruit nets. The exhibition was held in an internal circulation area of the institution, ensuring high visibility and promoting spontaneous engagement from students, teachers, and passersby.

As illustrated in Figure 2, the diversity and quality of the presented items were noteworthy: board games, stylized cars, airplanes, lanterns, and various toys were crafted with creativity and technical skill. The reuse of materials that would otherwise be discarded not only demonstrated students' manual and technical abilities but also fostered socio-environmental competencies such as ecological responsibility and innovative thinking. This aligns with the findings of Siqueira and Arrial [4], who highlighted how the

creation of toys from solid waste serves as a powerful tool to stimulate creativity and environmental commitment among elementary school children.

Figura 2 - Exhibition of objects produced by students using reusable materials.

The exhibition was designed as a space for dialogue and student protagonism. During the event, students were responsible for presenting their creations, explaining the materials used, the construction process, and the challenges faced during prototyping. This approach reinforced active learning and oral communication while also encouraging critical thinking about consumption, waste, and reuse—core elements for fostering circular citizenship and environmental responsibility [1][2].

In addition to its pedagogical focus, the project was enriched by a solidarity initiative: a collection box was placed beside the exhibition to gather non-perishable food items. The integration of environmental practice with social action gave the activity a broader formative dimension, promoting empathy, citizenship, and collective responsibility—a strategy aligned with sustainable education principles oriented toward community engagement and behavioral change. Nagatomo [6] similarly advocates for the integration of circular economy strategies with open technologies and social action. The exhibition and food collection represented the final stages of the Design Thinking process: testing and validation. The "test" phase was fulfilled through the presentation of the prototypes to the school community and the reception of direct feedback. The "validation" occurred both through the functional success of the objects and the social impact generated by the donations. This experience resonates with the work of Flowers et al. [7], who emphasized how practical activities using post-consumer waste can foster not only technical development but also shifts in attitudes toward Sustainability.

The experience also aligned with circular economy principles by giving new life to materials regarded as waste. This perspective echoes Bremgartner et al. (2024), who describe how educational workshops involving 3D printing waste contribute to cultivating a sustainable maker mindset and promoting material reuse as both an educational and ecological strategy [5].

By transforming discarded items into useful products, students demonstrated that sustainable innovation can be implemented in everyday school settings with low cost and high educational value. This finding is supported by

Çebi [3], who shows how the reuse of materials in art education enhances not only creative expression but also a broader aesthetic and ecological awareness.

4. FINAL CONSIDERATIONS

The pedagogical experience described in this study proved to be an effective strategy for integrating the concepts of sustainability, circular economy, and active learning within the context of technical education. By transforming waste into functional objects while simultaneously engaging in socially impactful actions, students were encouraged to reflect on their role as agents of change, promoting values such as empathy, environmental responsibility, and creativity.

The methodology based on Design Thinking proved appropriate for structuring the activity, as it allowed students to experience all stages of the creative process—from identifying challenges to delivering tangible solutions. The exhibition of prototypes and the solidarity initiative contributed to the consolidation of learning and strengthened the bond between school and community, expanding the scope of traditional technical training.

The proposed practice was shown to be replicable, low-cost, and highly didactic, standing out as a promising approach for interdisciplinary teaching and for promoting the Sustainable Development Goals (SDGs) within educational practices.

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References

[1] Kosta AD, Keramitsoglou KM, Tsagarakis KP. Circular economy and sustainable development in primary education. Frontiers in Sustainability 2025;6. https://doi.org/10.3389/frsus.2025.1414055.

[2] Nguyen TPL. Integrating circular economy into STEM education: A promising pathway toward circular citizenship development. Front Educ (Lausanne) 2023;8. https://doi.org/10.3389/feduc.2023.1063755.

[3] Çebi S. From Waste to Art: A Study on Student Creativity and Creative Expression through Recycled Materials in Art Education. Art Vision 2025;31:59–70. https://doi.org/10.32547/artvision.1542477.

[4] Siqueira V, de Arrial L. Educação ambiental através da reutilização de resíduos sólidos para a elaboração de brinquedos. Revista Thema 2018;15:927–42. https://doi.org/10.15536/thema.15.2018.927-942.865.

[5] BREMGARTNER JL, BREMGARTNER V, MANZATO L, SANTOS J. PROMOVENDO A SUSTENTABILIDADE POR MEIO DE UMA OFICINA DE RECICLAGEM DE RESÍDUOS DE IMPRESSÃO 3D. Revista Ibero-Americana de Estudos Em Educação 2024;19:e024064. https://doi.org/10.21723/riaee.v19iesp.1.18341.

[6] Nagatomo D. Research on Education for Sustainable Development with Design-Based Research by Employing Industry 4.0 Technologies for the Issue of Single-Use Plastic Waste in Taiwan. Sustainability 2024;16:9832. https://doi.org/10.3390/su16229832.

[7] Flowers J, Rauch C, Wierzbicki A. Teaching Upcycling to Impact Environmental Attitudes. Journal of Technology Education 2019;30:30–45. https://doi.org/10.21061/jte.v30i1.a.2.

[8] Chatzopoulos A, Tzerachoglou A, Priniotakis G, Papoutsidakis M, Drosos C, Symeonaki E. Using STEM to Educate Engineers about Sustainability: A Case Study in Mechatronics Teaching and Building a Mobile Robot Using Upcycled and Recycled Materials. Sustainability 2023;15:15187. https://doi.org/10.3390/su152115187.

[9] Brown T. Design Thinking. 2008.