Analyzing the Potential of a Serious Game for Solid Waste Management Awareness

Laura Ferreira Bezerra, Leonardo Tórtoro Pereira
Universidade Estadual Paulista (UNESP),
Instituto de Geociências e Ciências Exatas,
Rio Claro, Brasil
{lf.bezerra, leonardo.t.pereira}@unesp.br

Wilk Oliveira
Gamification Group, Faculty of Information Technology and Communication Sciences, Tampere University,
Tampere, Finland
wilk.oliveira@tuni.fi

***Abstract*—The low recycling rate in emerging countries contrasts with the efforts of public policies and educational initiatives, highlighting the need for new approaches to environmental awareness. This study proposes a serious game called "Sustainable Planet: Mission Preserve" as an educational tool for teaching sustainable practices. The game emphasizes solid waste management and proper disposal, engaging players in challenges that simulate these actions. To analyze the game's awareness potential, we conducted a quasi-experimental one-group study (N = 32) using pre- and post-interaction questionnaires with the game. This allowed us to assess its impact on participants' ability to classify waste type and its correct disposal. The results indicate a significant increase in participants' awareness, contributing to educational technologies for environmental education.**

***Index Terms*—Serious games, game-based learning, educational games, sustainability, quasi-experiment**

I. Introduction

Developing countries like Brazil, India, and Argentina struggle with solid waste management due to overwhelmed infrastructure and rapid urban growth [1]. Selective collection suffers from poor facilities and limited awareness, with cities collecting just 50-80% of waste, falling to 10% in poor areas [1]. Brazil recycles only 4% of its 77.1 million tons of annual waste, improperly disposing of 39% [2]. Youth education [3] and awareness campaigns [4] can improve practices, along with serious games for recycling education [5].

We propose "Sustainable Planet: Mission Preserve," a serious game to promote proper waste disposal. Designed for Brazil—aligning with national waste policy [6] and education standards[1]—it supports SDG 12.5[2] and can be adapted globally. Our Research Question (RQ) is: *Does the game improve waste management awareness?* A quasi-experiment (N=32) with pre-/post-test questionnaires showed significantly higher post-test scores, confirming its educational value.

II. Background and Related Work

Serious games merge education with interactivity to drive learning and behavior change, proving effective across ages and subjects like environmental education [5], [7]. Constructivist approaches show particular success [8]. Boncu *et al*. [5] analyzed 29 pro-environmental games, finding most improved knowledge or behavior, with settings similar to our pre-/post-test approach [9]. Unlike AR/VR solutions [10], we prioritize accessibility for Brazil's tech-limited schools. We also balance fun and learning by making the content part of the mechanics, and address Brazil's specific waste challenges, while the mechanics can be adaptable for other contexts.

III. Study Design

Our Unity game applies the COMBO methodology [11], blending constructivist learning with entertainment. Designed by an Environmental Engineer, it balances accessibility and education. We prioritized intuitive gameplay over quizzes through expert-developer collaboration, as shown in the appendix screenshots. This 2D top-down game (inspired by "Overcooked") teaches waste sorting using Brazil's CONAMA Resolution No. 275/2001 color standards. Players deliver waste to correct bins, earning 50 points per correct disposal, without penalty for mistakes. Levels progressively introduce 3-6 waste types, with a time-limited challenge requiring just one star to progress (Bronze: 500, Silver: 750, Gold: 1000).

To address our RQ, we developed pre- and post-test questionnaires in Google Forms[3], validated by Environmental Engineering experts and aligned with Brazil's waste policy [6] and education standards[4]. Following methodologies from [5], we measured knowledge improvement without providing answer feedback. Participants voluntarily proceeded to post-test after gameplay, ensuring actual interaction with the educational material. No ethical approval was required as no personal data was collected.

The anonymous questionnaire included an Informed Consent Form and instructions for game installation. Participants answered identical 12 questions before and after gameplay about the proper bin colors for common waste types: (1) paper (blue), (2) metal (yellow), (3) plastic (red), (4) glass (green), (5) organic (brown), (6) non-organic (gray), (7) electronics (orange), (8) healthcare (white), (9) wood (black), (10)

We thank *Instituto Coelho* for supporting the project https://institutocoelho.org.br/planetasustentavel/.

[1]https://www.gov.br/mec/pt-br/escola-em-tempo-integral/BNCC_EI_EF_110518_versaofinal.pdf

[2]https://sdgs.un.org/goals/goal12#targets_and_indicators

[3]https://forms.gle/PNt5MUByhMjxRg6F8

[4]https://www.gov.br/mec/pt-br/escola-em-tempo-integral/BNCC_EI_EF_110518_versaofinal.pdf

radioactive (purple), plus two trick items (polystyrene and building materials) that don't belong in colored bins.

We recruited 38 participants via social media, with most aged 18-30. After removing 6 incomplete responses and outliers (Z-score >2.5), we analyzed the data using Shapiro-Wilk (revealing non-normal distribution, p<.00) and Mann-Whitney U tests (appropriate for small samples [12]). We used rank biserial correlation for effect sizes [13].

IV. Results

Participants showed significant improvement in waste identification, with accuracy increasing from 53.39% (pre-test) to 67.19% (post-test). Electronics and wood recognition improved most (>100% increase), while untreated waste types (without designated bins) showed expected decreases as players tried guessing colors instead of selecting "unknown."

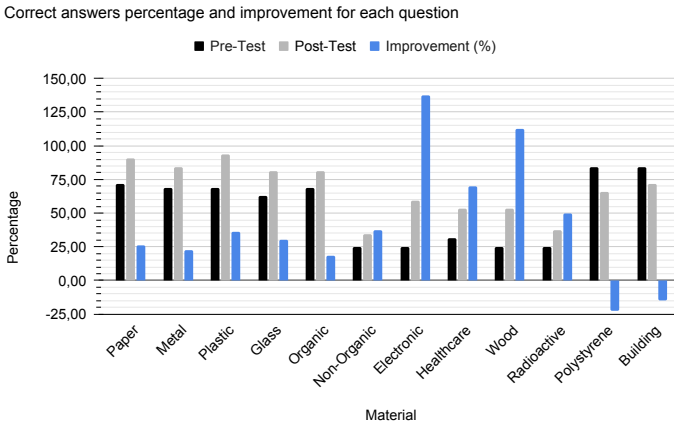

Fig. 1. Pre- and Post-test average accuracy for each material and percentage improvement.

Statistical analysis confirmed these gains: pre-test (M=0.533, SD=0.282) versus post-test (M=0.671, SD=0.222) showed significant difference (U=366.500, z=-4.511, p=.049) with large effect size (r=.560). These results demonstrate that our game effectively teaches proper waste sorting.

Our findings support existing evidence that educational games can effectively teach environmental concepts. Like [9], we used a quasi-experimental design, one of the few such approaches in this domain [5]. To our knowledge, this is the first robust study on solid waste management education in Brazil. Unlike VR [10], or Kinect-based solutions [14], our PC game offers greater accessibility in emerging economies.

Some limitations should be considered. The sample size (N=32) was insufficient for strong effect sizes, and using only Brazilian participants limits generalizability. Unknown demographics may introduce selection bias, as the game might appeal more to those already interested in gaming or environmental issues. Data collection relied on questionnaires vulnerable to response biases. The study measured only immediate impacts, not long-term retention. While we mitigated risks, we cannot guarantee that all players completed the game.

V. Concluding Remarks

This study examined the effectiveness of an educational game for teaching proper solid waste disposal. The results demonstrated improved user knowledge of correct waste classification, supported by both visual and statistical analysis of higher post-game scores. These strengthen existing literature on serious games' potential for environmental education. However, some limitations are the participants' backgrounds, the game's effectiveness across different cultures, and whether it produces lasting behavioral changes. Future work should address these and help the game cover more concepts.

Appendix

The study dataset can be accessed from this link: https://osf.io/jc7q6/

References

[1] I. R. Abubakar, K. M. Maniruzzaman, U. L. Dano, F. S. AlShihri, M. S. AlShammari, S. M. S. Ahmed, W. A. G. Al-Gehlani, and T. I. Alrawaf, "Environmental sustainability impacts of solid waste management practices in the global south," *International Journal of Environmental Research and Public Health*, vol. 19, no. 19, 2022.

[2] Sistema Nacional de Informações sobre Saneamento (SNIS), "Diagnóstico temático manejo de resíduos sólidos urbanos," 2023. [Online]. Available: https://antigo.mdr.gov.br/images/stories/ArquivosSNSA/Arquivos_PDF/Snis/RESIDUOS_SOLIDOS/DIAGNOSTICO_TEMATICO_VISAO_GERAL_RS_SNIS_2023_ATUALIZADO.pdf

[3] C. S. G. Penteado and M. A. S. de Castro, "Covid-19 effects on municipal solid waste management: What can effectively be done in the brazilian scenario?" *Resources, Conservation and Recycling*, vol. 164, p. 105152, 2021.

[4] J. Wang, E. Nketiah, X. Cai, B. Obuobi, G. Adu-Gyamfi, and M. Adjei, "What establishes citizens' household intention and behavior regarding municipal solid waste separation? a case study in jiangsu province," *Journal of Cleaner Production*, vol. 423, p. 138642, 2023.

[5] S. Boncu, O.-S. Candel, and N. L. Popa, "Gameful green: A systematic review on the use of serious computer games and gamified mobile apps to foster pro-environmental information, attitudes and behaviors," *Sustainability*, vol. 14, no. 16, 2022.

[6] Brasil, "Lei n ° 12.305, de 2 de agosto de 2010. institui a política nacional de resíduos sólidos; altera a lei n ° 9.605, de 12 de fevereiro de 1998; e dá outras providências," *Diário Oficial [da] República Federativa do Brasil*, 2010.

[7] J. Lopez, K. Rhodes, K. Begolli, A. Bustamante, and J. Ahn, "What "exactly" describes planning in a math game-based assessment? introducing fraction ball: Exactly," in *Proceedings of the 58th Hawaii International Conference on System Sciences*, 2025.

[8] F. Seraji and H. olsadat Musavi, "Does applying the principles of constructivism learning add to the popularity of serious games? a systematic mixed studies review," *Entertainment Computing*, vol. 47, p. 100585, 2023.

[9] R. Veronica and G. Calvano, "Promoting sustainable behavior using serious games: Seadventure for ocean literacy," *IEEE Access*, vol. 8, pp. 196 931–196 939, 2020.

[10] T. Theethum, S. Iamcharoen, A. Arpornrat, and S. Vittayakorn, "Sepbo: Trash separator bot vr game," in *2021 18th International Joint Conference on Computer Science and Software Engineering (JCSSE)*, 2021, pp. 1–6.

[11] M. d. S. Luccas and K. Castelo Branco, "Star owners: um modelo construtivista de desenvolvimento de serious games para jogo de ensino de teoria da computação," *Revista Brasileira de Informática na Educação*, vol. 31, pp. 27 883–1514–22 816–1–10–20 240 325, 2023.

[12] A. Field, *Discovering statistics using IBM SPSS statistics*. sage, 2013.

[13] E. E. Cureton, "Rank-biserial correlation," *Psychometrika*, vol. 21, no. 3, pp. 287–290, 1956.

[14] J. d. J. L. G. Ibánez and A. I. Wang, "Learning recycling from playing a kinect game," *International Journal of Game-Based Learning (IJGBL)*, vol. 5, no. 3, pp. 25–44, 2015.