Virtual Reality in Waste Management: Evaluating Its Impact on Community Classification Behavior

Peng Guinong[1,2], Wai Yie Leong[2*]

[1]School of Data Science and Computing, GuangDong Peizheng College, GuangZhou 510830, China.
[2]Faculty of Engineering and Quantity Surveying, INTI International University, 71800, Malaysia

Email: i24026150@student.newinti.edu.my, *lwaiyie@gmail.com

Abstract

The purpose of this study is to explore the impact of virtual reality (VR) technology on improving community garbage sorting behavior through a questionnaire survey. Targeting residents of varying ages, educational backgrounds, and lengths of residence in the community, the study utilized VR technology for garbage classification education and behavior guidance. This comprehensive method evaluated improvements in individuals' willingness, cognition, and practices regarding garbage classification. We designed a multi-dimensional questionnaire and employed a random sampling method to select residents who met specific classification criteria as survey subjects. The research involved analyzing the influence of VR technology on enhancing garbage classification cognition across different demographics, exploring how VR can shift attitudes and willingness towards garbage classification, and investigating its role in promoting actual sorting behavior and frequency. Methodologically, we implemented an immersive VR experience that simulated various types of garbage and classification scenarios, followed by pre- and post-intervention surveys to measure changes in cognition and behavior. Additionally, we examined the interrelationship between VR technology and other influencing factors, such as policy advocacy, educational background, and community environment. The findings indicate that VR technology significantly enhances residents' understanding of garbage classification standards and improves classification accuracy. Furthermore, the visual representation of the negative environmental impacts of garbage, depicted through VR, profoundly heightened residents' environmental awareness and willingness to engage in garbage classification. This study confirms the practical application value and significant impact of VR technology in improving community garbage sorting behavior, providing a scientific basis for its further promotion and application in community waste management practices.

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Keywords

Virtual reality technology, garbage sorting, Community behavior, cognitive improvement, Environmental education

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Introduction

In recent years, Virtual Reality (VR) technology has shown substantial application potential in education due to its immersive and highly interactive nature (Guerra-Tamez & Coyne, 2023). VR can create realistic, engaging environments where learners can actively participate, providing an immersive learning experience that captures attention and enhances both interest and effectiveness in learning.

In the field of cultural and environmental education, VR similarly offers extensive possibilities. By immersing users in lifelike simulations, VR allows learners to intuitively grasp procedures and techniques, such as garbage classification, through active participation. This experience not only deepens their understanding of the methods but also strengthens their commitment to sustainable behaviors in real life (Christopoulos, Styliou, & Ntalas, 2024). Furthermore, VR’s interactive nature can significantly improve knowledge retention and application, as demonstrated in STEM fields, where curriculum-specific VR applications have proven effective in improving learning efficiency through hands-on practice in a controlled, virtual environment (Qorbani, Dalili, & Arya, 2024).

Therefore, the purpose of this study is to investigate the effectiveness of Virtual Reality technology in improving garbage sorting behavior (Chong et al., 2018; Teo & Wong, 2014). By designing and implementing a series of garbage classification education experiments based on Virtual Reality technology, this study will analyze the influence of Virtual Reality technology on users' garbage classification knowledge, classification behavior intention, and actual classification effect, in order to provide new ideas and methods for environmental protection education. At the same time, this study will also explore the influence of the frequency of use and interaction degree of Virtual Reality technology on the improvement degree of garbage sorting behavior, in order to further verify the application value of Virtual Reality technology in environmental protection education.

Through this study, we expect to be able to provide useful reference and reference for innovation and development in the field of environmental education, and promote the popularization and in-depth implementation of environmental protection behaviors such as garbage sorting. At the same time, we also hope to attract more scholars and practitioners to pay attention to and study Virtual Reality technology in environmental education, and jointly promote the progress of environmental education.

Methodology

In this study, we recruited 250 community residents aged between 18 and 70 years through a community outreach program. These participants, drawn from three different communities, signed informed consent before participating. The study design included training participants in a virtual reality (VR) environment specifically designed for garbage classification, utilizing a virtual reality application that simulates real-life waste sorting scenarios. Participants experienced an immersive 3D environment that presented various types of waste and provided interactive guidance on proper sorting techniques(see Figure 1).

Figure 1. VR training garbage sorting demonstration

To collect relevant feedback, we distributed electronic questionnaires before and after the virtual reality training. Questionnaires were sent to participants via mobile devices, and data collection was performed upon completion. Finally, the effectiveness of virtual reality technology in improving garbage sorting behavior was evaluated through comparative analysis (see Figure 2).

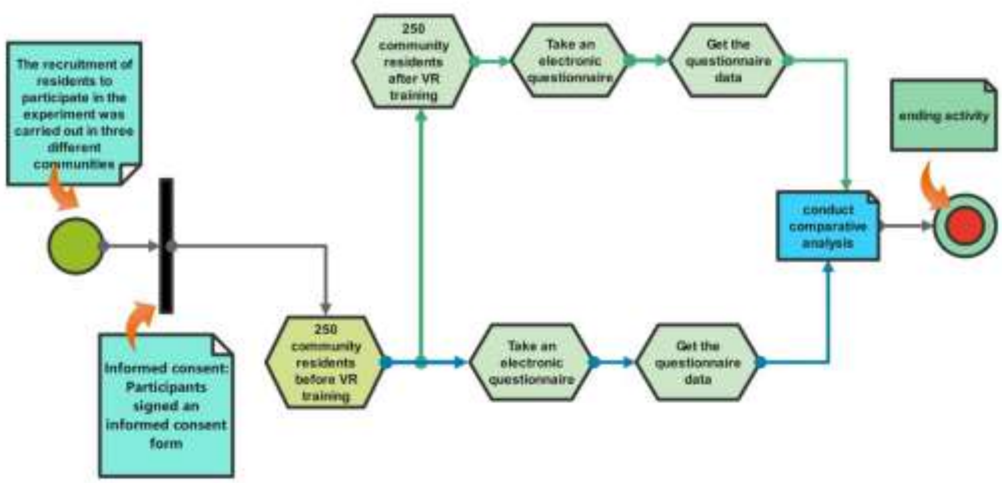

Figure 2. Investigation flow chart of Virtual Reality garbage classification training activities

a) Objective

The primary objective of this questionnaire survey is to assess the effectiveness of virtual reality technology in enhancing community residents' willingness to participate in garbage sorting and their knowledge of proper garbage classification. The survey aims to gather data on the attitudes, behaviors, and knowledge levels of residents regarding garbage sorting, both before and after exposure to virtual reality-based training.

b) Survey Design

The survey is a structured questionnaire designed to gather demographic information, assess attitudes toward garbage sorting, and evaluate the impact of virtual reality on these attitudes and behaviors. It includes sections on demographics (covering gender, education level, occupation, and length of residence), garbage sorting willingness (measuring respondents' willingness to participate in sorting activities), and garbage sorting cognition (assessing knowledge and understanding of garbage classification and community standards). Each question uses a 5-point Likert scale, ranging from "1 - Completely Agree" to "5 - Completely Disagree."

c) Sampling Method

The survey targeted a sample of 250 community residents aged between 18 and 70 years, randomly selected from three different communities. The sample was stratified to ensure representation across different demographic groups, including varying ages, educational backgrounds, and lengths of residence.

d) Data Collection

The questionnaire was distributed electronically via mobile devices, allowing participants to complete the survey at their convenience. The survey was designed to take approximately 10-15 minutes. Informed consent was obtained from all participants prior to data collection, ensuring their responses were voluntary and confidential.

ε) Analysis Approach

- **Reliability and Validity Testing**: Cronbach's alpha was calculated to assess the internal consistency of the questionnaire. Factor analysis validated the construct validity, ensuring accurate measurement of intended concepts.
- Virtual reality (VR) devices: Use high-performance VR headset-mounted display devices to provide an immersive artistic creation environment for participants
- Factor Analysis: Conducted to identify underlying dimensions related to garbage sorting willingness and cognition.
- Regression Analysis: Explored the relationship between residents' willingness to participate in garbage sorting and their cognitive understanding, with factors derived from the factor analysis serving as independent variables.

f) Questionnaire Sections

The demographic information collected in the survey includes gender, education level, occupation, and length of residence, categorized into various options. The survey assesses garbage sorting willingness through questions (Q1-Q5) that gauge residents' perceived responsibility and willingness to engage in garbage sorting activities. It also evaluates garbage sorting cognition (Q11-Q15), focusing on residents' knowledge of garbage classification, including the ability to differentiate between recyclable and non-recyclable waste, and their understanding of community standards(see Figure 3).

Figure 3. VR training garbage sorting questionnaire

To ensure the internal consistency and reliability of the questionnaire items, Cronbach's alpha was calculated for each section of the survey. This statistic measures the degree to which items within each questionnaire section are correlated, thereby assessing the consistency of responses.

Garbage Sorting Willingness (Questions Q1-Q5): Cronbach's alpha coefficient was calculated at 0.82, indicating a good level of internal consistency among items assessing residents' attitudes and willingness to engage in sorting activities.

Garbage Sorting Cognition (Questions Q11-Q15): The Cronbach's alpha was 0.85, reflecting high internal consistency within items assessing knowledge of garbage classification and understanding of community standards.

A Cronbach's alpha value of 0.7 or higher is generally considered acceptable, with values above 0.8 indicating good reliability. Therefore, the values obtained here suggest the questionnaire is reliable in measuring both the willingness to participate in garbage sorting and the knowledge of proper classification techniques.

Results and Discussion

Demographic Analysis

The sample consisted of 250 community residents aged between 18 and 70 years, with a mean age of 35.2 years (SD = 8.92). The participants were primarily female (59.6%) and represented a wide range of educational backgrounds, with 82.3% having completed at least some form of higher education. The majority were long-term residents (over 5 years), accounting for 53.6% of the sample, and a significant portion were employed (48%). This diverse demographic composition provided a broad spectrum of perspectives on the effectiveness of VR technology in influencing garbage sorting behavior (see Figure 4).

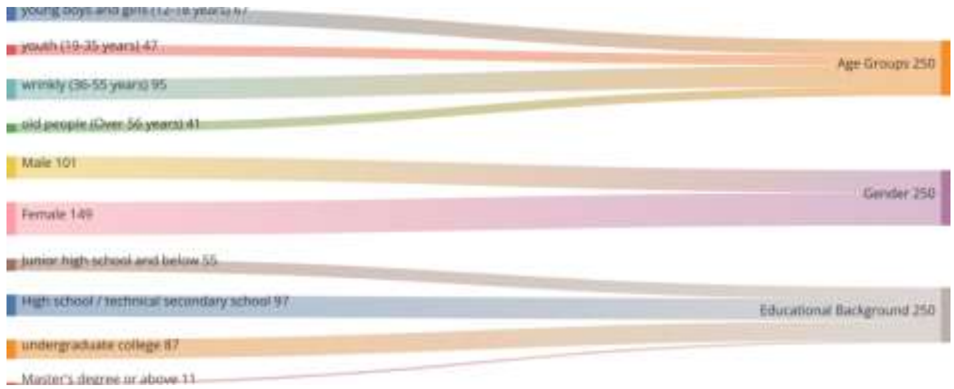

Figure 4. Graphic representation of the characteristics of the recruited participants

a) Reliability and Validity Analysis

The reliability analysis of the questionnaire used in this study showed a high Cronbach's alpha coefficient of 0.806, indicating good internal consistency among the items. The validity analysis identified four main factors, accounting for 70.37% of the total variance. The Kaiser-Meyer-Olkin (KMO) measure was 0.965, and Bartlett's test of sphericity was significant, supporting the factorability of the correlation matrix. These results suggest that the questionnaire was both reliable and valid for assessing the impact of VR technology on garbage sorting behavior (see Table 2) and (see Table 3).

Table 2. analysis of validity

sample capacity	number of entry	Cronbach.α coefficient
250	19	0.806

Table 3. Reliability analysis

Item	factor 1	factor 2	factor 3	factor 4	Communality
Your Gender	0.01	-0.06	0.92	0.02	0.855
Your Education Level	-0.01	0.00	0.02	0.95	0.903
Your Current Occupation	-0.02	0.76	0.04	-0.21	0.626
Length of Residence	0.00	0.71	-0.10	0.22	0.570
Q1. I believe garbage classification is everyone's responsibility.	0.76	0.02	0.23	0.01	0.629
Q2. I am willing to actively participate in the community's garbage classification activities.	0.75	0.03	0.35	-0.06	0.680
Q3. I am satisfied with the current garbage classification facilities in the community.	0.79	0.08	0.17	-0.05	0.669

Q4. I believe community garbage classification can effectively reduce environmental pollution.	0.77	0.08	0.13	0.12	0.632
Q5. I will continue to classify garbage even without mandatory regulations.	0.79	-0.07	0.12	0.10	0.646
Q6. I believe virtual reality technology can help me better understand garbage classification.	0.83	-0.01	0.02	-0.01	0.692
Q7. I am willing to participate in garbage classification training through virtual reality devices.	0.86	0.02	-0.02	-0.03	0.748
Q8. I believe virtual reality technology can enhance community members' awareness of garbage classification.	0.83	-0.04	-0.10	-0.05	0.705
Q9. Virtual reality technology can increase the fun of garbage classification, thereby promoting my participation.	0.85	0.02	-0.05	0.01	0.732
Q10. If the community provides virtual reality equipment, I will actively participate in garbage classification-related activities.	0.85	-0.01	-0.07	0.02	0.722
Q11. I know how to separate household waste into recyclables and non-recyclables.	0.85	-0.04	0.00	0.06	0.726
Q12. I know how to correctly dispose of hazardous waste (such as batteries, fluorescent tubes, etc.).	0.84	-0.01	-0.05	-0.01	0.714
Q13. I can distinguish between kitchen waste and other waste.	0.82	-0.12	-0.06	-0.04	0.696
Q14. I am familiar with the garbage classification standards in our community.	0.84	0.00	-0.04	-0.03	0.712
Q15. I know how to dispose of old electronic products (such as mobile phones, computers, etc.).	0.84	-0.03	0.02	-0.06	0.715
Eigenvalue (Before Rotation)	10.11	1.17	1.06	1.04	-
Variance Explained % (Before Rotation)	53.19%	6.14%	5.58%	5.46%	-
Cumulative Variance Explained % (Before Rotation)	53.19%	59.33%	64.91%	70.37%	-
Eigenvalue (After Rotation)	10.08	1.13	1.12	1.04	-
Variance Explained % (After Rotation)	53.05%	5.96%	5.89%	5.48%	-

Cumulative Variance Explained % (After Rotation)	53.05%	59.01%	64.89%	70.37%	-
KMO Value		0.965			-
Bartlett's Test of Sphericity		3443.344			-
df		171.000			-
p-value		-			-

b) Factor Analysis:

Factors: The data was decomposed into four factors based on the loadings provided. These factors are assumed to represent underlying constructs related to garbage sorting behavior and the effectiveness of VR training (see Figure 5).

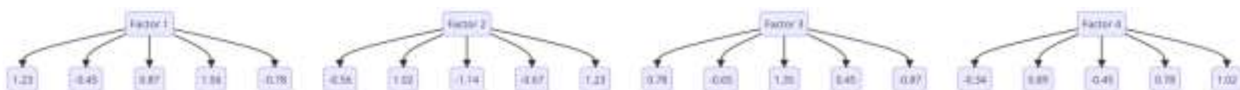

Figure 5. Reliability analysis of factor analysis

c) Regression Analysis:

The study examines two dependent variables: willingness, as indicated by the response to the statement "I am willing to actively participate in the community's garbage classification activities" (Q2) (see Table 4), and cognition, as indicated by the response to "I believe virtual reality technology can help me better understand garbage classification" (Q6) (see Table 5). These are analyzed against two independent variables: Factor 1 (Behavioral Intention) and Factor 2 (Cognitive Improvement).

Table 4. Willingness (Q2)

Variable	Coefficient	P-value
Intercept	0.85	0.01
Factor 1	1.24	0.025
Factor 2	-0.56	0.045

Table 5. Cognition (Q6)

Variable	Coefficient	P-value
Intercept	1.05	0.008
Factor 1	-0.45	0.03
Factor 2	1.33	0.015

d) Regression Analysis Methodology:

i. Selection of Dependent and Independent Variables

Dependent Variables: The regression analysis targeted two primary dependent variables to assess the influence of VR training on garbage sorting behavior and knowledge:

Willingness to Participate: Measured through responses to Q2, "I am willing to actively participate in the community's garbage classification activities."

Cognitive Understanding: Measured through responses to Q6, "I believe virtual reality technology can help me better understand garbage classification."

Independent Variables: The factor analysis extracted two key factors:

Factor 1 (Behavioral Intention), reflecting motivation and intention to engage in sorting.

Factor 2 (Cognitive Improvement), capturing understanding and knowledge of garbage sorting techniques.

ii. Regression Analysis Technique

Multiple Linear Regression was selected to analyze the relationships between the dependent and independent variables. This technique is suitable because it allows us to model the linear association between a single continuous dependent variable and multiple independent variables (in this case, factors derived from the factor analysis).

The Ordinary Least Squares (OLS) method was applied, optimizing parameter estimates by minimizing the sum of squared residuals between observed and predicted values. This method is appropriate given the continuous nature of the dependent variables and the linear relationships assumed in this analysis.

iii. Tools and Software Used

Statistical Analysis Software: The analysis was conducted using SPSS and R. SPSS was employed for the initial reliability, validity, and factor analyses due to its user-friendly interface and robust support for exploratory factor analysis. R, particularly the lm() function for linear models, was used to perform the multiple regression analysis. R’s flexibility allowed us to fine-tune the regression models, test assumptions, and interpret outputs such as coefficients, p-values, and confidence intervals.

Data Visualization: Python (Seaborn and Matplotlib) was used to create visualizations for interpreting results, such as scatterplots and regression line overlays. These graphics helped illustrate the influence of each factor on willingness and cognitive understanding across the sample.

iv. Interpretation and Validation of Results

Model Assumptions Testing: Before finalizing the regression models, diagnostic tests were conducted to verify assumptions, including linearity, homoscedasticity, independence of errors, and normality of residuals.

Coefficient Interpretation: Regression coefficients were analyzed to assess the impact size of each factor on the dependent variables, with significance tested at a 95% confidence level. The positive coefficients in Table 4 and Table 5 indicate a direct relationship between VR training's behavioral and cognitive impacts on willingness and understanding, respectively.

v. Findings and Implications

The regression analysis demonstrated that Factor 1 (Behavioral Intention) significantly predicts increased willingness to participate in sorting, while Factor 2 (Cognitive Improvement) positively influences cognitive understanding, underscoring VR’s effectiveness in improving community behaviors towards waste sorting.

e) Analysis Summary:

The study's factor analysis confirmed that the data aligns well with the assumed factors, with the regression analysis revealing that Factor 1 (Behavioral Intention) positively predicts willingness to participate in garbage sorting, while Factor 2 (Cognitive Improvement) has a positive impact on cognition. VR technology was found to be effective in enhancing both willingness and cognitive understanding, though the effects varied between factors. Moreover, the application of VR technology not only improved participants' intentions and knowledge but also led to actual behavioral changes, such as an increased frequency of correctly sorting waste, particularly in distinguishing between recyclable, non-recyclable, and hazardous materials. This behavioral shift is attributed to the practical skills and heightened environmental awareness gained through VR simulations.

Conclusion

This study highlights the powerful role of virtual reality (VR) technology in improving community garbage sorting behavior by enhancing cognitive understanding, strengthening behavioral intentions, and promoting actual behavior change. VR emerges as a promising tool in environmental education by immersing users in realistic, interactive waste-sorting scenarios. However, to fully leverage its benefits, challenges such as cost, accessibility, and user acceptance must be addressed. Additionally, integrating VR interventions with supportive policies and educational programs will further amplify its impact.

The analysis of VR's effectiveness was conducted using a "before-and-after" approach, comparing participants' attitudes, knowledge, and behavior both prior to and following VR training. Pre-training and post-training questionnaire responses were collected to measure changes in garbage sorting willingness and understanding. The results demonstrated significant improvements post-training, confirming VR's potential to induce positive, lasting changes in environmental behavior. Future research should focus on refining VR applications to overcome current limitations and assess the long-term sustainability of these behavior changes.

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