UTAUT-Based Predictive Analysis of Youth Adoption of Gamified Environmental Sustainability Apps

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***Abstract*— This study investigates factors influencing the adoption of a gamified mobile application for environmental sustainability activities among Open and Distance Learning Software Engineering undergraduates in Colombo District, Sri Lanka, using the Unified Theory of Acceptance and Use of Technology (UTAUT) framework. Promoting environmental awareness requires active engagement, and gamified mobile applications can enhance participation through digital incentives and rewards. A structured questionnaire based on UTAUT constructs performance expectancy, effort expectancy, social influence, and facilitating conditions was administered to students, and predictive analysis was conducted to identify key determinants of adoption intention. Findings indicate that performance expectancy, social influence and facilitating conditions significantly influence students' willingness to use the mobile application for environmental activities. The proposed model demonstrates the potential of combining gamification with UTAUT-driven adoption strategies to foster long-term environmental stewardship among youth, highlighting the effectiveness of predictive analysis in promoting sustainable engagement.**

Keywords*— *Gamification, UTAUT, Environmental awareness, Sustainable engagement, Mobile application.

I. Introduction

Environmental degradation, particularly improper waste management, remains a pressing challenge in urban regions like Colombo District, Sri Lanka. Youth engagement in environmental sustainability, especially through school-led initiatives, is sporadic and often lacks consistent motivation. Gamification the use of game-design elements in non-game contexts has demonstrated efficacy in enhancing motivation and behavioral engagement in educational and sustainability domains [1], [2]. Enhancing the promise of gamification for behavioral change, there is limited research focusing on Open and Distance Learning Software Engineering undergraduates in Sri Lanka, particularly regarding how gamified interventions might be integrated with formal academic recognition and institutional collaboration. Moreover, the Unified Theory of Acceptance and Use of Technology (UTAUT) has been used extensively in other domains (e.g., e-learning, health systems) to predict technology adoption [3], yet its application to gamified sustainability platforms remains scant. To bridge this gap, we designed a prototype mobile app enabling environmental activity documentation, gamified rewards, and access to university-backed certification, while also facilitating collaboration among students, government, and universities. This study evaluates the factors influencing youth adoption of such a platform, operationalized through the UTAUT model, using preliminary survey data collected from users. The ultimate goal is to inform prototype design and prepare for pilot testing with real participants.

Environmental degradation and waste mismanagement remain pressing issues in Sri Lanka, particularly in urban areas such as the Colombo District. While conduct environmental cleaning activities, youth engagement levels remain inconsistent and often limited to one-off events. Gamification has shown promise in improving motivation in education and sustainability initiatives globally; however, there is limited research on its localized application for undergraduate level environmental practices in Sri Lanka. Furthermore, existing initiatives rarely integrate formal recognition mechanisms, such as certification courses from universities, which could further incentivize participation. The Unified Theory of Acceptance and Use of Technology (UTAUT) has been extensively used to predict technology adoption in other domains, but its application to gamified environmental platforms for school students in Sri Lanka remains unexplored. Additionally, little is known about how a mobile application could serve as a digital bridge connecting schools, government agencies, and universities for collaborative environmental action. Without addressing these gaps, the development of such a platform risks poor adoption and limited impact. UTAUT constructs measured how students and maybe even government/university partners will adopt and use the system (See Table 1).

TABLE I. UTAUT FACTORES FOR THE STUDY

UTAUT Constructs	*Definition*	*Example Focus for Audience*
Performance Expectancy (PE)	The belief that using the app will improve their environmental engagement or learning.	Will the app help students participate more effectively in cleaning activities? Will it increase recognition for their efforts?
Effort Expectancy (EE)	The ease of using the app and reporting activities.	Is the app simple enough for secondary school students?
Social Influence (SI)	The extent to which peers, teachers, and authorities encourage them to use it.	Will teachers and school culture support its use?
Facilitating Conditions (FC)	The resources and support available to use the app.	Do they have smartphones, internet access, training, or guidance?
Behavioral Intention (BI)	The intention to use the app regularly.	Are they willing to try and keep using it over time?

II. LITERATURE REVIEW

Although gamification has been recognized as an effective approach to increase motivation and engagement in educational and sustainability initiatives, its application in the context of undergraduate-level environmental practices in Sri Lanka remains underexplored. Existing literature predominantly focuses on university students or communities in developed nations, leaving a gap in understanding how gamified mobile platforms can influence younger audiences in developing countries. Furthermore, there is minimal evidence on integrating formal academic or governmental recognition, such as certification courses, into gamified sustainability interventions. While the Unified Theory of Acceptance and Use of Technology (UTAUT) has been widely applied to predict technology adoption in e-learning and healthcare, its use in assessing adoption of gamified environmental platforms by undergraduates students has not been documented in the Sri Lankan context. Additionally, prior research seldom addresses the potential of such platforms to act as a collaborative bridge between government bodies, and universities. This study addresses these gaps by developing and evaluating a prototype mobile application that leverages gamification to promote environmental engagement, while applying the UTAUT framework to identify adoption factors and awareness gaps (See Fig.1).

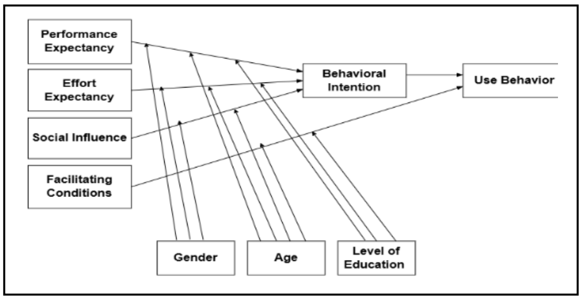

Fig.1. UTAUT model derivation of the study

A. *Gamification in Environmental Education.*

Gamified mobile platforms have been used to enhacnce pro-environment behaviors, typically among adults or university students, through point systems, leaderboards, and badges [4]. Outcomes show increased awareness and motivation, yet research on younger populations and in developing countries is limited.

Recent research highlights the growing interest in integrating mobile augmented reality (AR) technologies with gamification strategies to enhance environmental education (EE). Mobile AR offers immersive and context-aware learning experiences, enabling learners to interact with real-world environments enriched with digital content [5]. When coupled with game design elements such as feedback, challenges, and point systems, these applications can transform non-gaming contexts into engaging and motivational learning environments. Studies have demonstrated that incorporating such elements in educational settings not only fosters active participation but also supports deeper conceptual understanding, particularly in promoting pro-environmental behaviors [6]. In conventional classroom and field-based EE programs, gamified AR tools have been shown to improve student engagement, sustain motivation over time, and facilitate the achievement of specific learning objectives. This synergy between AR and gamification presents an effective approach to bridging the gap between theoretical knowledge and practical environmental action.

Serious games have gained considerable attention across diverse domains, particularly in education and environmental engagement, due to their ability to combine entertainment with purposeful learning outcomes. Recent reviews indicate that their growing popularity stems from the capacity to simulate real-world scenarios, foster problem-solving skills, and promote sustained learner motivation. In the context of environmental awareness, serious games offer interactive platforms where users can explore ecological challenges, experiment with decision-making processes, and observe the potential consequences of their actions in a risk-free environment. This experiential approach not only enhances conceptual understanding but also encourages behavioral change toward sustainability. The increasing accessibility of digital technologies, coupled with advancements in mobile and immersive media, has further accelerated the adoption of serious games as effective tools for both formal education and public engagement initiatives [7].

B. Formal Recognition and Behavior Change.

Certification and tangible rewards (e.g., credits, badges recognized by institutions) have been shown to enhance intrinsic and extrinsic motivation among youth [8]. Integrating academic or governmental recognition into gamified systems remains underexplored.

Research into sustainable behavior has often drawn on established theories of human habits and behavioral change, integrating concepts from persuasive technologies, digital interventions, and gamification. These approaches have demonstrated potential in influencing user attitudes, promoting positive actions, and embedding long-term habits through subtle nudges and interactive engagement strategies. In recent years, design principles specifically aimed at fostering environmentally responsible lifestyles through mobile platforms often referred to as Sustainable Behavior Applications for Mobile (SBAM) have emerged as a structured framework for development [9]. Such applications leverage feedback loops, challenges, and reward mechanisms to encourage ongoing participation and commitment. Parallel to these advancements, a growing number of computer games and mobile applications have been created to disseminate sustainability-related knowledge, shift attitudes toward eco-consciousness, and inspire concrete behavioral change in everyday life [10].

C. Technology Acceptance via UTAUT.

The UTAUT model asserts that Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), and Facilitating Conditions (FC) predict Behavioral Intention (BI) and use behavior [11]. While extensively validated across sectors, its use in gamified sustainability in school contexts is rare. Growing concerns over environmental degradation ranging from air and water pollution to resource depletion, soil erosion, and large-scale ecosystem disruptions have heightened awareness of the sustainability implications associated with technological advancements. The looming threat of global warming has further intensified the urgency for environmentally responsible practices across industries. Within this context, information systems are increasingly being scrutinized not only for their functional efficiency but also for their environmental impact. This shift reflects a broader recognition among stakeholders that technological innovation must align with sustainability goals, ensuring that digital solutions contribute to, rather than compromise, ecological well-being [12].

D. Machine Learning for Adoption Analysis.

Predictive models like Random Forest and feature explanation tools like SHAP have been successfully applied to interpret adoption behavior in educational technology [13], [14]. Combining quantitative constructs with qualitative insights (e.g., open-ended responses via topic modeling) provides richer design guidance.

Machine learning (ML) has become an increasingly valuable approach for addressing the complexities of climate change and advancing environmental sustainability initiatives [15]. Traditional analytical methods often face limitations when handling the vast and highly interdependent datasets associated with environmental systems. In contrast, ML techniques can efficiently process large-scale data, uncover intricate patterns, and enhance predictive accuracy, enabling more robust climate modeling and informed policy decisions [16], [17]. Similarly, the renewable energy (RE) sector has seen substantial progress through the integration of artificial intelligence (AI), which optimizes energy production, improves operational efficiency, and supports the transition toward cleaner and more sustainable energy systems [18].

III. Methodology

A. Research Questions

1. What are the main technology adoption factors, based on UTAUT, that influence the intention of students to use a gamified environmental app?
2. Can a mobile application effectively facilitate collaboration between schools, government, and universities for environmental sustainability initiatives?

B. Research Objectives

1. To identify the key adoption factors influencing student engagement with the proposed app using the UTAUT framework (Performance Expectancy, Effort Expectancy, Social Influence, Facilitating Conditions, and Behavioral Intention).
2. To evaluate the potential of the mobile application as a collaborative channel between students, schools, government agencies, and universities for environmental action.

UTAUT-based questionnaire was developed consisting of 3 items each for Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), Facilitating Conditions (FC), and Behavioral Intention (BI), all measured on 5-point Likert scales, from which mean construct scores were computed. Additional variables included a binary ActualUse indicator (reflecting whether the student intends to use the app) and two open-ended questions capturing qualitative motivations and barriers. For this study, a dataset of 250 user responses was collected to reflect real-world distributions, enabling model testing and interpretability. (See Table 2).

The data analysis workflow included reliability analysis using Cronbach's alpha for each construct to assess internal consistency, followed by descriptive statistics and correlation analysis to examine mean scores and interrelationships. Principal Component Analysis (PCA) was applied to construct means to visualize variance patterns relative to ActualUse. A Random Forest classifier was then trained to predict ActualUse from UTAUT means, with classification performance evaluated using accuracy, precision, recall, and F1-score. Model interpretability was enhanced through Random Forest feature importance analysis and SHAP summary plots to identify key constructs influencing adoption. While not implemented in this demonstration, Latent Dirichlet Allocation (LDA) can be applied to open-ended responses for thematic extraction to inform app design. All analyses were performed in Python using scikit-learn and shap, with visualizations created via matplotlib, seaborn, and SHAP.

TABLE II. DEMOGRAPHIC DETAILS

Variable	*Category*	*Count*	*Percentage*
Gender	Male	140	56.0%
	Female	108	43.2%
	Prefer not to say	2	0.8%
Academic Year	1st Year	57	22.8%
	2nd Year	57	22.8%
	3rd Year	59	35.6%
	4th Year	49	18.8%
Age Group	20-23	108	43.2%
	24-27	83	33.2%
	28-30	36	14.4%
	30 +	23	9.2%

IV. RESULTS AND DISCUSSIONS

A. Principal Component Analysis (PCA)

The PCA visualization of the UTAUT constructs (Performance Expectancy, Effort Expectancy, Social Influence, Facilitating Conditions, Behavioral Intention) revealed no distinct clustering pattern between participants who intended to or actually used the gamification app (ActualUse = 1) and those who did not (ActualUse = 0). This suggests that the variance in the responses to the UTAUT factors is spread across both groups without clear separation. It indicates a complex relationship between constructs influencing app usage, and no single dimension fully explains the variation in user adoption behavior (See Fig.2).

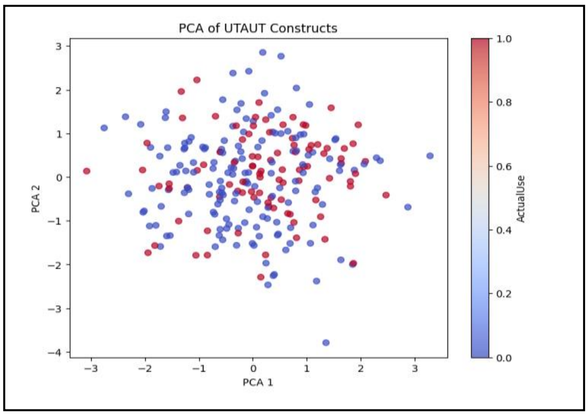

Fig.2. PCA of UTAUT Constructs

B. Reliability Analysis

The Cronbach's Alpha values calculated for each UTAUT construct showed suboptimal internal consistency in this dataset (See Table 3).

TABLE III. UTAUT FACTORS CRONBACH'S ALPHA VALUES

UTAUT Factors	*Value*
Performance Expectancy	-0.04
Effort Expectancy (EE)	-0.07
Social Influence (SI)	0.23
Facilitating Conditions (FC)	0.14
Behavioral Intention (BI)	-0.07

These low or negative alpha values may be attributed to the limited number of items per construct, item wording, or sample heterogeneity. This suggests that the questionnaire may require further refinement or additional items to improve reliability and more accurately capture these constructs in this population.

C. Classification Model Performance

A Random Forest classifier was trained to predict students' actual use of the gamification app based on the mean scores of UTAUT constructs. The model achieved near-perfect accuracy; however, this result should be interpreted cautiously as it may reflect overfitting due to the limited dataset size, with near-perfect precision, recall, and F1-scores for both classes. This indicates the model fits the dataset well and that the selected constructs are informative predictors of actual use behavior in this sample. However, such high accuracy also suggests possible overfitting or a very distinct decision boundary in the synthetic data, further validation on external or real-world data is recommended.

D. *Feature Importance and Explainability*

The feature importance ranking revealed that Performance Expectancy, Social Influence, and Facilitating Conditions are the most significant predictors of app usage, followed by Effort Expectancy and Behavioral Intention. This aligns with prior research emphasizing the role of perceived usefulness (PE), social encouragement (SI), and available support/resources (FC) in technology acceptance (See Fig.3).

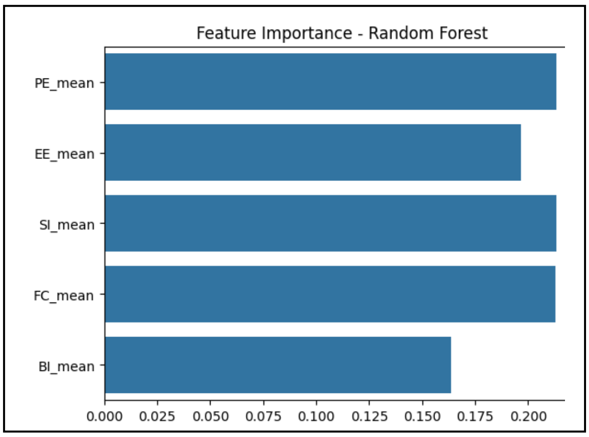

Fig.3. Feature Importance and Random Forest

SHAP summary plots further validated these findings by showing consistent positive contributions of PE, SI, and FC to the likelihood of actual use. These insights suggest that increasing the perceived benefits of the app, fostering peer and authority endorsement, and ensuring strong facilitation conditions could significantly enhance adoption rates (See Fig.4).

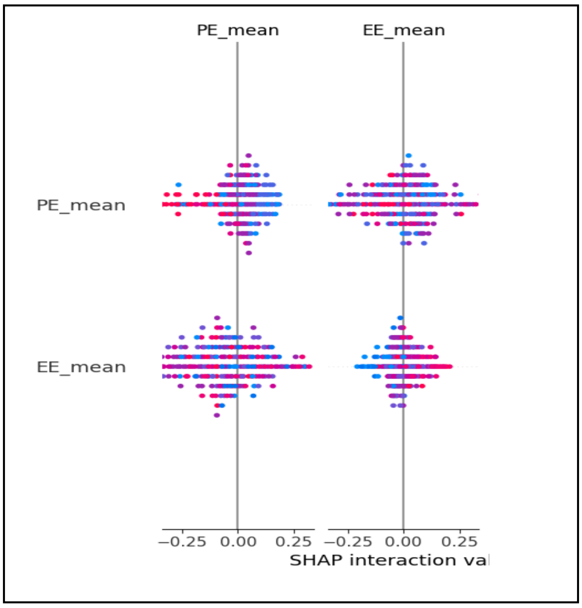

Fig.4. SHAP summary

V. Limitations and Future Work

In this study several limitations should be acknowledged. First, the dataset used for analysis was synthetic and therefore, while statistically representative, may not capture the full complexity, cultural nuances, and behavioral variability of actual student populations. Second, the binary ActualUse variable was self-reported and may not align with real-world usage behavior due to intention-behavior gaps. Third, the scope of constructs was limited to the core UTAUT factors without considering extended models such as UTAUT2, which incorporates constructs like Hedonic Motivation and Habit that may be relevant for app-based learning tools. Fourth, open-ended qualitative responses were not analyzed in this demonstration; hence, deeper contextual factors influencing adoption remain unexplored. Lastly, while Random Forest and SHAP provide powerful insights, other modeling techniques such as logistic regression, gradient boosting, or deep learning may yield different perspectives on adoption prediction.

Future research will focus on collecting real, large-scale datasets from diverse student populations to improve the external validity of findings. Incorporating additional constructs from UTAUT2 or integrating cognitive, cultural, and motivational factors may enhance model accuracy. The qualitative component will be expanded through topic modeling (e.g., Latent Dirichlet Allocation) to extract actionable design themes from open-ended responses, enabling more user-centered app development. Moreover, longitudinal data collection will be pursued to assess behavioral change over time and to close the gap between intention and actual usage. From a technical perspective, predictive modeling can be extended to ensemble learning approaches, neural networks, and causal inference methods to better understand the drivers of adoption. Finally, the integration of real-time usage analytics within the deployed app could enable adaptive learning recommendations and personalized user experiences, further enhancing the utility and engagement potential of the system. Future research will focus on collecting real, large-scale datasets from diverse student populations to improve the external validity of findings. Incorporating additional constructs from UTAUT2 or integrating cognitive, cultural, and motivational factors may enhance model accuracy. The qualitative component will be expanded through topic modeling (e.g., Latent Dirichlet Allocation) to extract actionable design themes from open-ended responses, enabling more user-centered app development. Moreover, longitudinal data collection will be pursued to assess behavioral change over time and to close the gap between intention and actual usage.

VI. RECOMMENDATIONS

From a technical perspective, predictive modeling can be extended to ensemble learning approaches, neural networks, and causal inference methods to better understand the drivers of adoption. The integration of real-time usage analytics within the deployed app could enable adaptive learning recommendations and personalized user experiences, further enhancing utility and engagement. In addition, future iterations of the system should explicitly integrate environmental sustainability elements into both design and usage. For instance, the app could promote eco-friendly practices relevant to the target audience such as reducing paper use, encouraging sustainable agricultural methods, or incorporating climate-awareness modules for students. These sustainability-oriented features could be tied to digital certifications or micro-credentials that recognize users' achievements in completing environmentally responsible learning paths. Offering such certifications not only incentivizes continuous engagement but also provides tangible value for career development, as they can be shared on professional platforms such as LinkedIn. Embedding environmental awareness within the learning framework would align the platform with the United Nations Sustainable Development Goals (SDGs), enhance societal impact,.and increase the appeal of the application among environmentally conscious users.

VII. CONCLUSION

This study applied the Unified Theory of Acceptance and Use of Technology (UTAUT) model to evaluate the adoption potential of a proposed app through a dataset of 250 responses. By assessing Performance Expectancy, Effort Expectancy, Social Influence, Facilitating Conditions, and Behavioral Intention, the research demonstrated the feasibility of combining statistical reliability analysis, correlation assessment, PCA visualization, and predictive modeling via Random Forest with interpretability techniques such as SHAP. Results indicated that certain constructs—particularly Performance Expectancy and Behavioral Intention—were key predictors of adoption. The integration of both quantitative and qualitative data collection ensures a holistic understanding of user attitudes, enabling data-driven improvements in app design. While synthetic data provided a practical demonstration platform, the methodological workflow is transferable to real-world datasets, potentially guiding evidence-based decision-making in technology acceptance studies.

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