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Bridging the Attitude–Behaviour Gaps in Water Sustainability through Digital Gamification: A Quantitative Study in Sarawak, Malaysia

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Abstract

Digital gamification is increasingly recognised as an innovative pedagogical strategy for promoting pro-environmental behaviours among students. However, its effectiveness in translating positive environmental attitudes into consistent behavioural outcomes remains underexplored, particularly within Southeast Asia. This study investigates whether a gamified learning environment can enhance the alignment between attitudes and sustainable water-use behaviours among urban secondary school students in Malaysia. Employing a quasi-experimental design, 63 Form 1 students from two public high schools participated in an eight-week intervention. The treatment group engaged with a gamified module delivered through Minecraft Education Edition, while the control group received conventional instruction. Pre- and post-test questionnaires assessed students' attitudes and behaviours toward water sustainability. Findings reveal a stronger correlation between attitude and behaviour in the treatment group ($r = .647$, $p = .001$) than in the control group ($r = .538$, $p = .002$), suggesting that gamification supports improved attitudinal-behavioural alignment. These results underscore the pedagogical potential of digital gamification in bridging the attitude–behaviour gap and promoting sustainable practices among students. Future research should adopt longitudinal and mixed methods approaches to evaluate the long-term impacts and generalizability across diverse educational contexts.

Keywords: Environmental Education, Water Literacy, Water Sustainability, Water Educational Technology, Game-Based Learning

Introduction

Water sustainability is a growing global concern, exacerbated by rising consumption, pollution, and climate variability. These stressors threaten freshwater security and demand integrated responses. In Malaysia, environmental pressures are compounded by infrastructural constraints, making it crucial to instil responsible water-use behaviours from an early age through public education (Maniam et al., 2021; Chan et al., 2021). Although students generally express positive attitudes toward water conservation, a significant discrepancy remains between these attitudes and their actual behaviours (Ahmad et al., 2024; Hashim et al., 2021).

Digital gamification has emerged as a promising tool to strengthen the link between awareness and action in domains requiring behavioural change, including environmental sustainability and education (Janakiraman et al., 2021; Phuong, 2024). Gamification incorporates game design elements such as points, rewards, feedback, and challenges into non-game settings to increase engagement and motivation. These psychological drivers are widely recognised as essential in shaping attitudes and promoting behavioural shifts (Chen, 2018; Cheng et al., 2022). While many studies report short-term improvements in behavioural intention due to gamification, its long-term impact and scalability remain under debate (Erdbrink et al., 2019; Ourdas & Ponis, 2023).

Theoretical models such as the Theory of Planned Behaviour (TPB) and Self-Determination Theory (SDT) have been widely used to explain the mechanisms through which gamification influences human behaviour. These frameworks emphasise the significance of attitude, motivation, and perceived control in influencing decision-making. However, current research lacks consensus on how individual game mechanics affect psychological constructs and behavioural outcomes. Elements such as narrative immersion, social comparison, personalisation, and goal clarity are believed to play varying roles across contexts (Chen, 2018; Cheng et al., 2022), but few studies have systematically compared these effects within formal education settings.

In the Southeast Asian context, and particularly in Malaysia, the integration of gamification into the formal education system remains underdeveloped. Although students are increasingly digitally literate, classroom strategies continue to rely heavily on conventional instruction (Phuong, 2024). This disconnect is particularly problematic in urban areas where digital infrastructure and student exposure to technology are relatively high. Secondary school students in urban Malaysia represent a key demographic for digital environmental interventions, given their access to mobile devices and familiarity with gamified platforms. Despite these enabling conditions, little research has been conducted on how gamification might reinforce pro-environmental attitudes and behaviours in this context.

The Role of Attitude in Driving Sustainable Water Behaviour

Attitude is a central construct in the TPB, representing individuals' evaluations of specific behaviours. In the context of water conservation, positive attitudes typically reflect beliefs about the value, feasibility, and ethical importance of water-saving practices. Empirical

studies have repeatedly shown that favourable attitudes are associated with stronger intentions to engage in sustainable behaviours (Ahmad et al., 2024; Onyenankeya et al., 2018). When supported by moral norms and emotional engagement, attitudes can also predict actual behaviour, as shown in agricultural, domestic, and institutional contexts (Valizadeh et al., 2018).

Nonetheless, the link between attitudes and behaviour is neither automatic nor absolute. The attitude-behaviour gap is well-documented across various cultural and demographic contexts. For instance, residents in low-income housing in India, despite endorsing conservation values, did not consistently practise them due to systemic and habitual constraints (Thakur et al., 2022). Similarly, university students in Portugal continued to consume bottled water despite high environmental awareness (Sousa et al., 2023). These discrepancies point to the importance of situational and enabling factors, such as convenience, infrastructure, and social norms, in mediating behavioural outcomes (Pervaiz & Iqbal, 2023).

In Malaysia, studies also show that demographic factors, including gender, age, and location, significantly influence how attitudes translate into action. Saad and Mahmud (2023) found that female students reported stronger environmental knowledge and attitudes than males, potentially indicating higher behavioural alignment. Meanwhile, Norkhaidi et al. (2021) highlighted that environmental literacy does not uniformly predict sustainable behaviour, as socio-demographic influences often override knowledge effects. Ahmad et al. (2024) demonstrated that, among urban consumers, attitudes and subjective norms were more reliable predictors of water conservation than awareness alone.

Attitudes show greater behavioural predictive power when reinforced by intrinsic motivation and self-concept. Shahangian et al. (2024) demonstrated that attitudes mediate the influence of moral norms and environmental self-identity on sustainable water practices. Fatoki (2021) observed that heightened environmental concern strengthened the relationship between attitudes and behaviour, especially in the hospitality sector. However, Gibson et al. (2023) noted that while intrinsic motivation aligns well with attitude-driven action, extrinsic motivators such as rewards may produce inconsistent outcomes if they overshadow internal commitment.

Despite these findings, the predictive validity of attitudes remains contested. Several studies report weak or statistically insignificant associations between attitudes and behaviour, often due to methodological issues like self-reporting bias or short-term measurement windows (Qing et al., 2012; Shaw et al., 2011). Moura et al. (2017) and Dilek & Sevilay (2013) emphasised the limitations of cross-sectional designs and called for longitudinal or quasi-experimental methods to provide clearer evidence on causal relationships.

Gamification as a Bridge between Attitudes and Behaviour

Gamification offers a potential mechanism for closing the attitude–behaviour gap by reinforcing motivational pathways. School-based gamification activities have demonstrated promising results. For example, Di Paolo and Pizziol (2023) reported that simple photo-based challenges enhanced student engagement and increased awareness of water conservation. Similarly, community programmes incorporating competitive elements led to measurable

improvements in self-reported sustainable behaviours (Bilancini et al., 2023; Boncu et al., 2022).

Game elements such as points, badges, leaderboards, and social comparisons have been widely used to strengthen environmental self-efficacy and reinforce positive attitudes. Erickson et al. (2012) documented a 6.6% decrease in household water use when gamified comparisons were introduced. Moreno-Cadavid et al. (2019) found that primary students who interacted with 3D sandbox games developed stronger conservation attitudes. These outcomes suggest that specific game mechanics can foster deeper attitudinal change when they align with user values and emotional triggers.

Psychological theories provide a useful lens for interpreting these findings. Cheng et al. (2022) confirmed that gamified learning outcomes correlate with TPB constructs, including attitudes and behavioural intention. Zhang and Anwar (2025) argued that gamification is most effective when it fulfils basic psychological needs, such as autonomy and competence, consistent with SDT. Furthermore, intrinsic motivation has been shown to play a critical role in converting attitudinal gains into lasting behaviour (Cao & Cheng, 2024). However, excessive reliance on extrinsic motivators may reduce internalisation and sustainability of outcomes.

Despite these encouraging results, previous studies often suffer from short intervention periods, reliance on self-reports, or lack of contextual sensitivity. Boncu et al. (2022) and Bilancini et al. (2021), for example, evaluated only immediate post-intervention effects. Others, such as Moreno-Cadavid et al. (2019), used culturally homogeneous samples, which limits the generalizability of their findings. Addressing these limitations, the present study adopts a quasi-experimental design over an eight-week period to evaluate whether a gamified digital intervention can meaningfully strengthen the relationship between attitude and behaviour in urban Malaysian classrooms.

Research Objective

This study aims to assess the extent to which digital gamification enhances the alignment between environmental attitudes and sustainable water-use behaviours among secondary school students in urban Malaysia. Specifically, it examines whether a structured gamified learning intervention can narrow the attitude–behaviour gap and promote durable conservation practices in a formal educational context.

Method

Research Design

The study employed a quasi-experimental design (Johnson & Christensen, 2014), utilising a non-equivalent pre-test–post-test control group format. Both treatment and control groups completed a pre-test to ensure comparability at baseline and to account for potential selection effects. This design was chosen because random assignment was not possible, yet the approach provides sufficient internal validity for assessing attitudinal and behavioural outcomes (Johnson & Christensen, 2014).

Participants and Context

The research involved Form 1 students from two government high schools situated in urban areas of Sarawak, Malaysia. A purposive selection strategy was applied, guided by three conditions:

(1) Participants had not yet covered the "Water Resources" unit in their Geography curriculum.
(2) The schools had functioning computer laboratories with reliable internet facilities.
(3) Geography teachers were adequately trained in information and communication technologies (ICT).

From the pool of eligible schools, two were drawn at random. One was designated as the intervention site while the other served as the control, thereby reducing the likelihood of treatment contamination. A total of 63 students participated, comprising 31 in the treatment group and 32 in the control group.

Research Instrument

The questionnaire was adapted from the Water Literacy Scale developed by Sözcü and Türker (2020). To ensure contextual relevance to the Malaysian setting, several items were reworded and aligned with themes identified in the reflective report by Maniam et al. (2024), particularly those related to urban water-use challenges and conservation practices. Attitudes were measured using 15 items, while behaviours were assessed through another 15 items, both using a five-point Likert scale ranging from *"strongly disagree" (1) to "strongly agree"* (5). The instrument underwent expert review for content validity, involving specialists in pedagogy, environmental management, and water education. The experts confirmed the suitability of the items for evaluating students' attitudes and behavioural tendencies toward sustainable water practices. Reliability analysis conducted in a pilot test yielded Cronbach's Alpha coefficients of 0.805 for attitudes and 0.772 for behaviours, indicating acceptable levels of internal consistency.

Module Topics

The intervention was systematically structured over an 8-week period, during which the treatment group engaged with eight sub-modules. Each sub-module was carefully designed to address specific topics and strategies related to water literacy, ensuring progressive learning from foundational knowledge to applied practice. The weekly topics, strategies, and intended learning outcomes for the treatment group are presented in Table 1.

Meanwhile, the control group was also exposed to the same eight sub-modules; however, the content was delivered using traditional teaching approaches such as lectures, textbook-based exercises, teacher-led discussions, and written assignments. The corresponding weekly topics, strategies, and water literacy dimensions for the control group are outlined in Table 2.

Table 1
Weekly topics, Strategies, and Water Literacy Dimensions (Treatment group)

Week	Topic	Strategy	Water Literacy Dimension	Intended Learning Outcome
1	Water?	Inquiry Mission	Knowledge	Stimulate curiosity by exploring the essential nature of water; establish a baseline understanding of water as a life-sustaining resource.
2	Water Sources in Malaysia	Exploration Quest	Knowledge & Attitudes	Identify and map Malaysia's water sources; foster appreciation of local natural resources and their importance.
3	Global Water Crisis	Discovery Challenge	Knowledge & Attitudes	Investigate global water issues through simulation to build awareness of worldwide scarcity and foster empathy for affected communities.
4	Water Crisis in Malaysia	Problem-Solving Task	Attitudes & Behaviours	Analyse local water crises; propose and test solutions, reinforcing responsibility and problem-solving skills.
5	Our Water System	Construction Project	Knowledge & Behaviours	Model Malaysia's water supply system; understand infrastructure while practising resource management and collaborative building.
6	Sustainable Dam	Creative Build	Knowledge, Attitudes & Behaviours	Design a sustainable dam that considers both ecological and social impacts, thereby strengthening systems thinking and innovation.
7	Sustainable Agriculture	Applied Design	Knowledge & Behaviours	Develop water-efficient agricultural systems; apply conservation practices to real-world food production challenges.
8	Save Our Water Campaign	Innovation Build	Attitudes & Behaviours	Create a digital advocacy campaign; encourage communication, civic responsibility, and commitment to sustainable water practices.

Table 2
Weekly topics, Strategies, and Water Literacy Dimensions (Control group)

Week	Topic	Conventional Strategy	Water Literacy Dimension	Intended Learning Outcome
1	Water?	Lecture & textbook-based introduction	Knowledge	Provide a foundational understanding of water's essential role in life and ecosystems.
2	Water Sources in Malaysia	Teacher-led discussion with map-reading	Knowledge & Attitudes	Identify Malaysia's water sources; foster basic appreciation of national water resources through guided instruction.
3	Global Water Crisis	Reading comprehension & class Q&A	Knowledge & Attitudes	Examine global water issues from textbook materials; develop awareness of scarcity and inequality across regions.
4	Water Crisis in Malaysia	Case study worksheet & teacher explanation	Attitudes & Behaviours	Analyse examples of local water crises; discuss possible solutions with teacher guidance to reinforce responsibility.
5	Our Water System	Diagram drawing & note-taking	Knowledge & Behaviours	Learn about Malaysia's water supply system; describe processes while practising organisation through diagrams.
6	Sustainable Dam	Group discussion & written assignment	Knowledge, Attitudes & Behaviours	Explore the concept of dams and sustainability; evaluate social and ecological impacts in writing.
7	Sustainable Agriculture	Classroom exercise & teacher feedback	Knowledge & Behaviours	Understand basic principles of water-efficient agriculture; apply conservation practices conceptually through written exercises.
8	Save Our Water Campaign	Poster-making & oral presentation	Attitudes & Behaviours	Design a campaign poster; practise communication and civic responsibility through classroom presentations.

Validation of the Digital Gamification Module

The digital gamification module, *Water Warriors: Save the World*, built on the Minecraft Education Edition platform, underwent validation by a panel of nine experts. These experts represented diverse backgrounds, including gamification, educational technology, human–computer interaction, and environmental education. They evaluated the module against four criteria: technical robustness, user interface design, multimedia integration, and instructional interactivity.

Each criterion was rated on a seven-point Likert scale (1 = strongly disagree; 7 = strongly agree), and mean scores were interpreted shown in Table 3. The findings consistently showed high acceptance, with mean scores of 6.6 for technical quality, 6.7 for interface design, 6.7 for multimedia use, and 6.8 for interactivity, resulting in an overall mean of 6.7, which falls within the "very high" category.

Table 3
Interpretation of Mean Score

Mean Score	Level
5.81 – 7.00	Very High
4.61 – 5.80	High
3.41 – 4.60	Moderate
2.21 – 3.40	Low
1.00 – 2.20	Very Low

Ethical Considerations

This study was carried out in full compliance with the ethical research standards set by the Ministry of Education, Malaysia. Prior to data collection, formal approval was granted by the Educational Policy Planning and Research Division (EPRD), Ministry of Education, Malaysia. In accordance with these requirements, informed consent was obtained from all student participants, and parental or guardian consent was also secured, given the involvement of minors. Participants and their parents/guardians were provided with clear information regarding the objectives, procedures, potential benefits, and their rights within the study.

Confidentiality and anonymity were strictly safeguarded throughout the research process; no personal identifiers were collected, and all data were treated as strictly confidential. Participation was entirely voluntary, with both students and parents/guardians informed of their right to withdraw at any stage without negative consequence. These procedures ensured that the study was conducted responsibly, with respect for the dignity, rights, and welfare of all participants, in accordance with established ethical guidelines for educational and behavioural research.

Intervention Procedures

The intervention lasted for eight weeks, with each weekly session lasting 90 minutes and integrated into regular Geography lessons. The digital gamification module was aligned with the Form 1 curriculum on water resources, but specifically targeted the reinforcement of attitudinal and behavioural dimensions. Students in the treatment group engaged with scenario-based challenges in the Minecraft virtual environment, which required decision-making, collaboration, and reflection on water-related practices, as illustrated in Figures 1 and 2. The control group received conventional instruction without gamified elements. Post-tests were administered at the end of the intervention to determine the extent of change in students' attitudes and behaviours.

Figure 1: A student completing a Minecraft-based water conservation challenge

Figure 2: Students participating in a shared Minecraft world using join mode for collaborative gameplay

Data Analysis

Baseline Equivalence Between Groups (Pre-Test)

Prior to examining the relationship between students' attitudes and sustainable water-use behaviours, an Independent Samples t-test was conducted to ensure that both the treatment and control groups were statistically equivalent at the pre-test stage. As shown in Table 4, there were no significant differences between the two groups in terms of attitude ($t(61) = -0.208$, $p = .836$) and behaviour ($t(61) = -0.788$, $p = .434$). These results indicate that both groups began the study at a comparable level, thus allowing for a valid comparison of the relationships between variables within each group. Following this verification, a Pearson correlation analysis was conducted to assess the relationship between attitude and behaviour within each group at the post-test stage.

Table 4
Independent samples t-test for both attitude and behaviour scores at the pre-test stage

Variable	Control		Treatment				
Pre-Test	*M*	*SD*	*M*	*SD*	*df*	*t*	*p*
Attitude	57.7500	1.56576	57.6452	2.37414	61	-0.208	.836
Behaviour	56.9375	3.02610	56.3266	3.16636	61	-0.788	0.434

Correlation between Attitude and Behaviour

The results, presented in Tables 5 and 6, reveal a statistically significant positive correlation between students' attitudes and their sustainable water-use behaviours in both the treatment and control groups. However, the treatment group exhibited a slightly stronger correlation, suggesting a potential reinforcing effect from the gamified intervention.

Table 5
Correlation between Attitude and Behaviour in the Treatment Group

Variable		PostScore -Attitude	PostScore -Behaviour
PostScore_Attitude	Pearson Correlation	1	.647**
	Sig. (2-tailed)		.001
	N	31	31
PostScore_Behaviour	Pearson Correlation	.647**	1
	Sig. (2-tailed)	.001	
	N	31	31

*** Correlation is significant at the 0.01 level(2-tailed)*

As shown in Table 5, the treatment group demonstrated a moderately strong and significant correlation between post-intervention attitude and behaviour scores ($r = .647$, $p = .001$). This suggests that students who developed more positive attitudes were more likely to engage in behaviours that align with those attitudes. These findings reinforce the theoretical proposition that positive attitudinal dispositions play a critical role in shaping behavioural responses, particularly when supported by an engaging and interactive learning environment. The statistically significant correlation at the 0.01 level indicates a robust association between the two constructs in the treatment group. This finding provides empirical support for the claim that gamification may enhance the alignment between students' environmental attitudes and their behaviours.

Table 6
Correlation between Attitude and Behaviour in the Control Group

Variable		PostScore -Attitude	PostScore -Behaviour
PostScore_Attitude	Pearson Correlation	1	.538**
	Sig. (2-tailed)		.002
	N	32	32
PostScore_Behaviour	Pearson Correlation	.538**	1
	Sig. (2-tailed)	.002	
	N	31	31

*** Correlation is significant at the 0.01 level(2-tailed)*

Similarly, as shown in Table 6, the control group also demonstrated a moderate but significant correlation between attitude and behaviour (r = .538, p = .002). This indicates that even without exposure to the gamified intervention, students with more favourable attitudes towards sustainable water use were generally more likely to demonstrate corresponding behaviours. The presence of a significant correlation in both groups affirms the foundational assumption that attitude is a key predictor of behaviour.

Discussion

This study examines the relationship between students' attitudes toward sustainable water use and their behaviour, particularly within a gamified learning context. The pre-test results indicate no statistically significant differences between the control and treatment groups in attitude and behaviour, thereby confirming baseline equivalence. This strengthens the internal validity of the study, as any post-test differences can be attributed to the gamification intervention rather than pre-existing group differences.

Correlation analysis shows a significant positive relationship between attitude and sustainable behaviour in both groups, with a higher correlation coefficient in the treatment group (r = .647) than in the control group (r = .538). Although the difference is moderate, its pedagogical implications are noteworthy, suggesting that gamification may reinforce the attitude–behaviour link. These findings are consistent with Janakiraman et al. (2021), who found that digital games enhance pro-environmental attitudes and promote real behavioural change. This aligns with the Theory of Planned Behaviour (TPB), wherein attitude is a key predictor of behavioural intention. When learning experiences are engaging and interactive, attitudes are more likely to translate into sustainable practices.

The role of gamification in strengthening the attitude–behaviour relationship is evident in the treatment module. Features such as rewards, challenges, immediate feedback, and social interaction provided students with opportunities to align values with action in a simulated environment. Bilancini et al. (2023) reported that game-based education among nearly 2,000 Italian primary school students improved sustainable water use behaviour, with effects lasting up to six months post-intervention. These findings parallel the results of the current study, in which students in the treatment group demonstrated a stronger attitude–behaviour link compared to the control group.

A particularly valuable dimension of this intervention was the use of Minecraft Education to allow students to visualise and simulate real-world water sustainability systems. For instance,

student groups designed a virtual dam and reservoir to model sustainable water storage, regulation, and controlled distribution (Figure 3). This activity encouraged them to understand the engineering and ecological aspects of water retention systems. In addition, they constructed a digital irrigation system representing sustainable agriculture by incorporating rainwater harvesting channels and crop rotation strategies (Figure 4). These virtual constructions provided students with interactive, hands-on experiences that mirrored real-world environmental challenges and solutions. The visual and participatory nature of these tasks not only enhanced their conceptual understanding but also facilitated the internalisation of pro-environmental values through experiential learning.

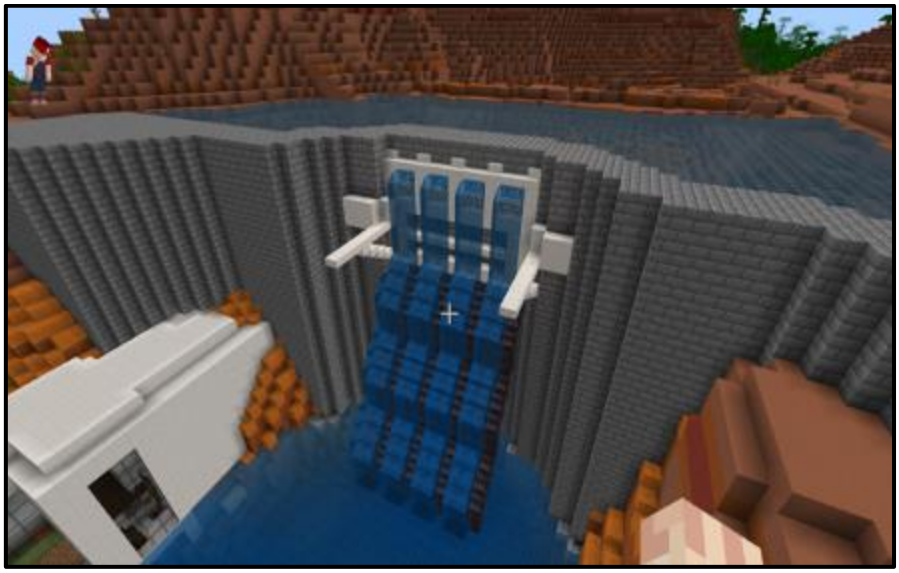

Figure 3. A virtual dam and reservoir created by student groups in Minecraft Education to represent sustainable water storage.

Figure 4. An agricultural system developed by student groups in Minecraft Education,using rainwater and irrigation channels for sustainable farming.

Furthermore, Di Paolo and Pizziol (2023), through the BLUTUBE program, observed that primary students engaging in gamified challenges, such as board games, city games, and photographic tasks related to sustainable behaviour, displayed significant improvements in

awareness and behaviour regarding water usage. These results indicate that gamification contributes not only to enjoyment but also to learning experiences that enable students to translate attitudes into concrete action.

The significant correlations in both groups highlight the importance of a positive attitude in shaping sustainable behaviour. However, the stronger attitude–behaviour linkage in the treatment group suggests that gamification accelerates and strengthens the process by which attitudes evolve into behaviours. Hamdan, Lara-Sánchez, and Arufe-Giráldez (2023) found that students participating in environmental digital games exhibited not only increased knowledge but also heightened emotional and social engagement. Such engagement likely stabilises attitudes, increasing the probability of long-term behavioural transformation.

In the context of water education, these findings carry important implications. Gamified tasks, such as those implemented in Minecraft Education, allow students to directly observe the link between their choices and environmental outcomes. When students make sustainable decisions within simulated environments, they immediately see the positive or negative consequences, which reinforces the understanding that consistent action must follow positive attitudes for meaningful change to occur.

The broader literature further suggests that the effectiveness of gamification is influenced by contextual factors and demographics. Bilancini et al. (2023) reported stronger intervention impacts among younger students, who responded more readily to competitive and collaborative elements. Therefore, gamified environmental education must be designed to suit students' age, culture, and literacy levels to optimise learning outcomes. Additionally, Di Paolo and Pizziol (2023) emphasised that community involvement, particularly through activities such as parental participation in photography challenges, plays a key role in sustaining water-conscious behaviour. This highlights the value of gamification that engages students not only at the individual level but also through broader social networks, thereby reinforcing the internalisation of sustainable attitudes.

Although the observed correlation differences are moderate, the findings offer significant practical insights. A key challenge in environmental education lies in ensuring that pro-environmental attitudes are translated into long-term behaviours. The present study reinforces prior evidence (Bilancini et al., 2023) that educational games can effectively support sustainable behaviour even after the intervention period ends. Thus, embedding gamification into the curriculum can serve not only to boost knowledge acquisition but also to establish mechanisms that promote the consistency between attitude and behaviour over time.

Implications and Future Directions

The findings of this study carry significant pedagogical and policy implications for environmental education, particularly within the Southeast Asian context. First, the enhanced correlation between pro-environmental attitudes and sustainable water behaviours in the gamified group underscores the transformative potential of digital gamification in formal schooling. This suggests that integrating game-based learning into national curricula can bridge the persistent attitude–behaviour gap, which has historically impeded the effectiveness of traditional educational methods. Policymakers and curriculum designers

should therefore consider adopting gamified interventions as a standard pedagogical tool, especially for environmental topics where behaviour change is critical.

From an instructional design perspective, the success of the Minecraft-based intervention suggests that game mechanics, such as narrative-building, real-time feedback, and collaborative challenges, are not merely engagement tools but also function as cognitive and emotional reinforcers. These elements provide students with experiential learning environments that simulate real-world sustainability challenges, thereby fostering deeper internalisation of environmental values.

However, the moderate strength of the observed correlations implies that gamification, while effective, is not a panacea. Its impact is contingent upon thoughtful integration with curricular goals, demographic alignment, and the provision of extrinsic and intrinsic motivational scaffolds. Accordingly, educators must be trained not only in game mechanics but also in the psychological theories underpinning behaviour change, such as the Theory of Planned Behaviour and Self-Determination Theory.

Future research should explore the long-term sustainability of gamification-induced behavioural changes through longitudinal designs that track actual water usage over extended periods. Additionally, mixed-method approaches combining behavioural tracking, in-depth interviews, and observational data can yield a more nuanced understanding of how attitudes evolve into sustained practices. It is also essential to replicate this study across rural settings, different cultural contexts, and varying age groups to assess the generalisability of the findings.

Moreover, the inclusion of community stakeholders, such as parents, local authorities, and non-governmental organisations, could amplify the social reinforcement mechanisms critical for long-term behavioural change. Gamified interventions that extend beyond the classroom and into students' homes and communities may offer a more holistic and durable impact.

Conclusion

This study contributes to the growing body of evidence supporting the use of digital gamification in environmental education. By demonstrating a stronger alignment between attitudes and sustainable behaviours among students exposed to a gamified intervention, this offers empirical validation for incorporating game-based methods into pedagogical strategies that target behavioural change. Rather than reiterating implications already discussed, this conclusion affirms that the real value of gamification lies in its ability to transform passive learning into participatory experiences. Through structured engagement, students are encouraged not only to understand sustainability concepts but also to embody them through simulated practice.

Crucially, this study moves beyond theoretical assumptions by employing a quasi-experimental design that captures the immediate impact of gamified learning on attitudinal-behavioural consistency. While the findings are promising, they also signal the need for continued refinement, both in research design and pedagogical implementation, to ensure such strategies result in lasting behavioural transformation.In sum, digital gamification, when

thoughtfully integrated into formal curricula, represents not just a technological innovation but a meaningful shift in how environmental responsibility can be cultivated in the classroom.

Theoretical and Contextual Contributions

This study makes several specific theoretical and contextual contributions to the literature on water literacy and pro-environmental behaviour. Theoretically, it extends Ajzen's (1991) Theory of Planned Behavior (TPB) to the context of sustainable water use by demonstrating that attitudinal change fostered through a structured digital game-based learning module is systematically associated with students' self-reported sustainable water-use behaviours in an authentic school setting. By operationalising water literacy as a construct that explicitly links attitudinal and behavioural dimensions, rather than focusing on knowledge alone, the study responds to and refines recent conceptualisations of water literacy proposed by McCarroll and Hamann (2020), Boon (2024), and Imaduddin and Eilks (2024), all of whom call for more integrated, education-focused frameworks and measurement approaches. In doing so, the findings provide empirical evidence that a carefully designed digital gamification approach can serve as a pedagogical mechanism to strengthen the attitude–behaviour link that underpins many models of environmental and water-related behaviour.

Contextually, the study contributes rare empirical data from urban public secondary schools in Sarawak, Malaysia, where water security and sustainable resource management are increasingly important but remain under-represented in empirical research on digital pedagogy. By aligning a digital game-based module with the national lower-secondary Geography syllabus and broader national concerns about water sustainability, the study offers context-specific guidance for teachers, curriculum designers, and policymakers on how to embed digital gamification into everyday classroom practice to nurture more sustainable water-use behaviours among adolescents.

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***Informed Consent*:** Written consent was obtained from all student participants and their legal guardians prior to data collection.

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