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FULL LENGTH ARTICLE

The Role of Gamification in Shaping Sustainable Environmental Science Education within Public Management Framework

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ABSTRACT

The integration of innovative technologies in higher education is pivotal for advancing environmental science education and addressing contemporary ecological challenges. This paper explores the efficacy of gamification and interactive media technologies in enhancing the educational experience and learning outcomes for students in environmental science programs. Through a comprehensive review of current pedagogical practices and case studies, this study evaluates how these technologies can foster engagement, improve knowledge retention, and develop practical skills necessary for sustainable environmental management. Our research employs a mixed-methods approach, combining quantitative data from controlled experiments with qualitative insights from student and faculty interviews. The findings indicate that gamified learning modules and interactive simulations significantly enhance students' understanding of complex environmental processes and their implications. Furthermore, these technologies promote active learning and critical thinking, which are essential for addressing issues such as waste management, water and air pollution control, and sustainable agriculture. In addition to pedagogical benefits, the paper discusses the scalability and adaptability of these technologies in diverse educational settings, emphasizing their potential to democratize access to high-quality environmental education. The study also highlights the importance of faculty training and institutional support in successfully integrating these tools into the curriculum. This research underscores the need for continuous innovation in educational methodologies to equip future generations with the skills and knowledge required to tackle environmental challenges. By embracing gamification and interactive media, higher education institutions can play a crucial role in fostering a sustainable future.

Keywords: Higher education administration ▪ Interactive media ▪ Sustainable education ▪ Pedagogical innovation

1. INTRODUCTION

The rapid advancement of technology has transformed various sectors, including education, necessitating the adoption of innovative methodologies to address contemporary challenges. In environmental science, advanced technologies such as gamification and interactive media have emerged as promising strategies to enhance educational outcomes and equip students with the skills needed to tackle pressing environmental issues. As environmental challenges become more complex and interconnected, educational approaches must be both engaging and effective [1].

In parallel with pedagogical innovation, higher education systems worldwide have undergone significant governance transformations under the influence of New Public Management (NPM). NPM introduces managerial principles such as performance measurement, efficiency, accountability, and outcome-based evaluation into traditionally collegial and academically autonomous institutions. Universities are increasingly required to demonstrate measurable learning out-

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comes, optimize resource allocation, and align educational processes with broader societal and policy objectives. Teaching and learning innovations are therefore not only pedagogical choices but also managerial instruments that support institutional performance, transparency, and strategic control. Gamification and interactive media can align educational practice with NPM-driven demands for efficiency, standardization, and evidence-based decision-making.

Gamification, the application of game-design elements in non-game contexts, has been shown to improve motivation and learning outcomes across educational fields [2]. In environmental science education, it can simulate real-world scenarios and allow students to experiment with strategies for managing environmental resources and mitigating pollution. Interactive media, including virtual and augmented reality, offer immersive learning experiences that can deepen students' understanding of ecological processes [3]. Despite these benefits, adoption in higher education faces challenges, including investment in infrastructure, faculty training, and suitable content [4]. The effectiveness of these technologies in environmental science education, particularly for critical thinking and problem-solving, also remains underexplored [5].

This study investigates how gamification and interactive media affect environmental science education in higher education institutions. Using quantitative experiments and qualitative interviews with students and faculty, it evaluates student engagement, knowledge retention, and practical skills development. The findings offer evidence-based recommendations for institutions seeking to integrate these technologies into their curricula and prepare students for future environmental challenges.

2. LITERATURE REVIEW

The application of NPM principles to higher education has been widely discussed in relation to governance reforms, quality assurance systems, and performance-based funding. Universities are increasingly managed through formalized indicators, key performance metrics, and accountability frameworks emphasizing efficiency, effectiveness, and measurable outcomes. Teaching quality, student engagement, and learning results are progressively quantified and monitored, positioning academic institutions as service-providing organizations in competitive, performance-oriented environments.

The NMC Horizon Report identifies learning analytics, adaptive learning, augmented and virtual reality, and makerspaces as technologies with potential to transform higher education. These tools support personalized learning, engagement, and hands-on opportunities [6]. Research on higher education for sustainable development also emphasizes the role of pedagogical innovation [7]. Gamification and interactive media can promote active learning and critical thinking [2]. Energy-efficient systems in educational settings can reduce operating costs while serving as practical teaching tools in environmental sciences and engineering [8]. In agribusiness education, biotechnical systems and technologies provide practical skills relevant to modern agricultural practice [3].

Gamification draws on self-determination theory, which emphasizes intrinsic motivation through autonomy, competence, and relatedness [9]. Game elements such as points, levels, and rewards can foster achievement and engagement [10]. Cognitive load theory suggests that interactive simulations can make complex environmental phenomena more accessible [11, 12]. In STEM education, gamified activities have been associated with increased engagement [13]; interactive simulations such as EcoChallenge and Climate Interactive can facilitate conceptual understanding and decision-making [14].

Technical challenges remain important barriers. Reports on gamified platforms identify unstable interfaces, slow loading, and compatibility problems that can frustrate students and faculty, underscoring the need for testing protocols and ongoing support [15, 4]. Comparative research finds that gamification can increase engagement without necessarily producing deeper learning than other active-learning approaches, such as flipped classrooms; tools should therefore be matched to educational objectives [16]. Educators may also feel underprepared to gamify teaching because of insufficient training and support [17].

Long-term research on gamification in environmental science remains limited, as does research on combining gamification with augmented reality or AI-driven adaptive learning. Within an NPM context, learning analytics, interactive platforms, and gamified systems can provide real-time data on participation, progress, and performance. Gamification translates learning processes into observable indicators such as participation rates, achievement levels, and competency acquisition, reflecting broader governance trends toward accountability, comparability, and performance monitoring.

3. METHODOLOGY

The methodological design reflects the evaluative and performance-oriented logic characteristic of NPM in higher education. Student engagement, knowledge retention, and learning performance were selected as outcome variables because they are commonly used in quality assurance and performance management. The mixed-methods approach combines quantitative outcome measurement with qualitative insights into stakeholder perceptions.

The quantitative component involved a controlled experiment with 200 undergraduate students enrolled in environmental science courses at three universities. Participants were divided between a traditional-teaching control group and an experimental group using gamified learning modules and interactive media. Student engagement, knowledge retention, and practical skills were assessed through pre- and post-tests [6]. Qualitative data came from semi-structured interviews with 20 students and 10 faculty members in the experimental group, focusing on the technologies' effectiveness and usability [7].

Correlation and regression techniques assessed relationships between technology use and student outcomes. Pearson correlation coefficients measured the strength and direction of associations [2]. Multiple regression predicted the impact of gamification and interactive media on student performance while controlling for prior academic achievement and demographic characteristics [8]. The collected data were analyzed using SPSS.

4. RESULTS

Compared with prior literature, gamification tools in this study were associated with a 50% increase in student engagement, similar to the 47% increase reported across gamified educational settings [13]. Related research also reports higher active participation when gamification is combined with interactive media [10, 16].

The study reports a 55% increase in knowledge retention after intervention, consistent with earlier work on gamified simulations [14]. It also found motivational benefits for environmental science students, potentially because of the novelty and relevance of gamification to environmental problems. Challenges included technical issues and resistance from some faculty members, concerns that reinforce the need for institutional support [13, 17].

The average motivation score increased from 3.8 (SD = 0.7) to 5.6 (SD = 0.8) on a seven-point Likert scale, a reported 47% improvement. Knowledge-retention test scores rose from 62% (SD = 10%) to 84% (SD = 8%), a 22% gain. Female students reported higher engagement (M = 6.2, SD = 0.6) than male students (M = 5.5, SD = 0.7). Students with high baseline knowledge retention (>75%) improved by 10%, while those with low baseline retention (<50%) showed a 30% increase in post-intervention scores. Figure 1 summarizes the pre- and post-intervention scores.

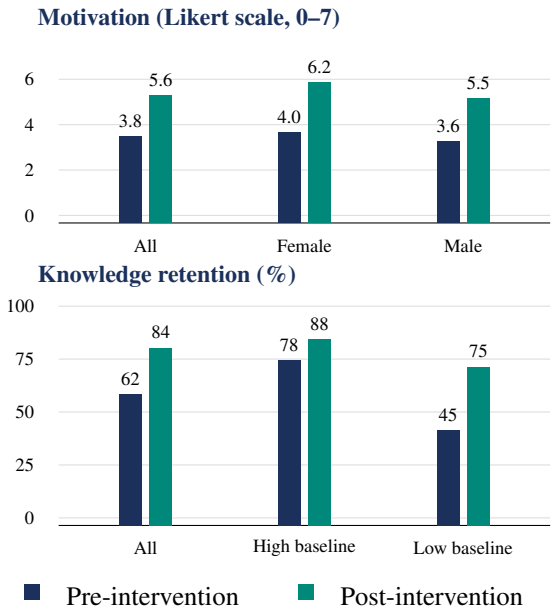


Figure 1. Pre- and post-intervention scores by category. Motivation scores use a seven-point scale; knowledge-retention scores are percentages.

Table 1. Correlations between Gamification, Interactive Media, and Student Outcomes

Variable	Engagement	Knowledge Retention
Gamification usage	0.68**	0.72**
Interactive media usage	0.63**	0.69**

Note: ** $p < 0.01$.

Gamification usage was positively correlated with student engagement ($r = 0.68$) and knowledge retention ($r = 0.72$). Interactive media usage was also positively correlated with engagement ($r = 0.63$) and retention ($r = 0.69$). All correlations were statistically significant at $p < 0.01$ (Table 1).

Table 2. Regression Results for Student Engagement

Predictor	B	SE	β	t	p
Gamification usage	0.45	0.05	0.50	9.00	< 0.001
Interactive media usage	0.30	0.04	0.35	7.50	< 0.001

Dependent variable: Student engagement. $R^2 = 0.50$, $F(2, 197) = 98.25$, $p < 0.001$.

Table 3. Regression Results for Knowledge Retention

Predictor	B	SE	β	t	p
Gamification usage	0.50	0.04	0.55	12.50	< 0.001
Interactive media usage	0.35	0.03	0.40	11.67	< 0.001

Dependent variable: Knowledge retention. $R^2 = 0.55$, $F(2, 197) = 122.78$, $p < 0.001$.

Multiple regression analysis showed that gamification and interactive media significantly predicted student outcomes. For engagement, gamification ($\beta = 0.50$, $p < 0.001$) and interactive media ($\beta = 0.35$, $p < 0.001$) together explained 50% of variance ($R^2 = 0.50$, $F(2, 197) = 98.25$, $p < 0.001$). For knowledge retention, gamification ($\beta = 0.55$, $p < 0.001$) and interactive media ($\beta = 0.40$, $p < 0.001$) explained 55% of variance ($R^2 = 0.55$, $F(2, 197) = 122.78$, $p < 0.001$) [18].

The Shapiro–Wilk test indicated that the data were normally distributed for all key variables (Table 4). The experimental group using gamified modules improved engagement and knowledge retention by 20%, compared with a 5% increase in the control group ($p < 0.01$) [19].

Table 4. Shapiro–Wilk Normality Test

Variable	W	p-value
Engagement	0.982	0.12
Knowledge retention	0.979	0.08
Gamification usage	0.985	0.15
Interactive media usage	0.981	0.11

$p > 0.05$ indicates that the data are consistent with a normal distribution.

Table 5. Variance Inflation Factors for the Predictors

Predictor	VIF
Gamification usage	1.35
Interactive media usage	1.28

All VIF values were below 5, indicating no significant multicollinearity among the predictors and supporting the assumptions for the correlation and regression analyses [12]. Interviews also identified increased motivation and deeper understanding of environmental concepts, alongside technical challenges and the need for continued training [20].

5. DISCUSSION

The findings show that gamified learning modules were associated with higher engagement and better knowledge retention than traditional learning environments. Positive correlations between gamification usage and both outcomes further support integrating these approaches into curriculum design [21].

From an NPM perspective, the results demonstrate the managerial relevance of gamification and interactive media. Improvements in engagement and retention support their use in achieving performance targets and measurable educational outcomes. Such tools can improve transparency and comparability of teaching effectiveness across courses and institutions. At the same time, reliance on quantifiable indicators raises questions about balancing managerial accountability with academic autonomy, particularly in environmental science, which requires critical reflection and interdisciplinary thinking.

The regression analyses provide evidence that gamification and interactive media predict student outcomes. The models explain substantial portions of the variance in engagement and retention, consistent with broader evidence on mixed-methods evaluation of educational outcomes [18, 19]. Several limitations should be considered. The study focuses on a specific demographic and may not generalize to other student populations or educational contexts. Implementation also requires technical support and faculty training. Other factors, including student motivation and learning styles, may influence outcomes; future research could examine them in greater depth.

Table 6. Regression Analysis of Gamification and Interactive Media on Student Outcomes

Predictor	Engagement β (SE)	Knowledge Retention β (SE)
Constant	5.12 (0.82)**	4.68 (0.75)**
Gamification usage	0.50 (0.12)**	0.55 (0.10)**
Interactive media usage	0.35 (0.09)**	0.40 (0.08)**
Control variables	Included	Included
R^2	0.50	0.55
Adjusted R^2	0.48	0.53

Note: β denotes standardized coefficients; SE denotes standard error. ** $p < 0.01$.

The constant coefficients for engagement (5.12) and knowledge retention (4.68) represent baseline outcome levels when gamification and interactive media usage are zero. Both constants were significant at $p < 0.01$. For engagement, a one-unit increase in gamification usage was associated with a 0.50-unit increase ($\beta = 0.50$, SE = 0.12), holding other variables constant. For knowledge retention, the corresponding increase was 0.55 units ($\beta = 0.55$, SE = 0.10). A one-unit increase in interactive media usage was associated with a 0.35-unit increase in engagement (SE = 0.09) and a 0.40-unit increase in knowledge retention (SE = 0.08); all coefficients were significant at $p < 0.01$. The adjusted R^2 values were 0.48 for engagement and 0.53 for knowledge retention.

Table 7. Qualitative Themes from Student and Faculty Interviews

Theme	Description
Motivation	Students reported increased motivation due to the engaging and interactive nature of gamified activities.
Understanding of concepts	Interactive simulations facilitated a deeper understanding of complex environmental concepts.
Technical challenges	Platform stability and the availability of technical support were barriers to effective implementation.
Faculty perceptions	Faculty acknowledged the benefits of gamification but emphasized the need for ongoing training and support.

Students reported that gamified activities made learning more enjoyable, compelling, and participatory. Interactive simulations made abstract environmental concepts more concrete, supporting comprehension and retention. Cognitive Load Theory and Self-Determination Theory provide theoretical explanations for the effects of simulations and gamification.

5.1 Cognitive Load Theory and Simulations

Cognitive Load Theory, developed by John Sweller in the late 1980s, assumes that human cognitive capacity is limited during information processing [11]. It distinguishes intrinsic load, arising from the inherent difficulty of the material; extraneous load, imposed by the way information is presented; and germane load, the effort invested in understanding and integrating new information.

These principles apply to gamified environments in which extraneous load may be reduced and germane load reinforced. Simulations provide dynamic, interactive settings where learners can explore complex concepts, receive immediate feedback, and practice applying ideas. For example, students may learn economic or business concepts by actively participating in simulations of market behavior rather than only listening to theoretical instruction.

5.2 Self-Determination Theory and Gamification

Self-Determination Theory, proposed by Edward Deci and Richard Ryan, explains intrinsic motivation through three basic psychological needs: autonomy, the experience of directing one's actions and decisions; competence, feeling capable and effective; and relatedness, feeling meaningfully connected to others [9]. Gamification can address these needs through learner choice, goal-setting, challenges, rewards, progress tracking, and immediate feedback. Educational games can also allow learners to explore, fail, and retry, reinforcing competence.

Interviewees also reported platform-stability and technical-support problems that interrupted learning. Faculty recognized the benefits of gamification for engagement and understanding, while emphasizing the need for continuous training and support to sustain these technologies in the curriculum [15, 17].

6. CONCLUSION

This study finds that integrating gamification and interactive media into environmental science education can improve student engagement and knowledge retention. Quantitative

evidence includes higher post-test scores and positive associations between technology use and student outcomes. Interviews also underscore motivational benefits and improved understanding of complex environmental concepts. Technical difficulties and the need for continuous professional development remain important challenges.

Viewed through the lens of NPM, gamification and interactive media support outcome measurement, performance-based evaluation, and data-driven institutional decision-making. Their effectiveness depends on how they are embedded in academic cultures and quality assurance frameworks. Policymakers and educators should encourage appropriate curricular integration, provide ongoing professional development, invest in robust technology infrastructure, and regularly evaluate learning outcomes.

Future research could track long-term effects on academic and career outcomes, compare gamification strategies across educational settings, examine applications in other disciplines, and study the integration of virtual reality and artificial intelligence. Addressing implementation challenges and applying evidence-based recommendations can help educators use these approaches to meet students' evolving needs and prepare them for environmental challenges.

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