Gamification and Geotechnologies for university teaching on Socio-Environmental Risks

Juan José Garcés-Gálvez – University of Santiago of Chile, Chile 0000-0002-4801-3885
Marcos Medina-Tapia – Polytechnic University of Catalonia, Spain 0000-0002-3961-5075
Ignacio Yáñez-Henríquez – University of Santiago of Chile, Chile – Esri Chile 0009-0006-0360-1559

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Correspondencia a través de **ORCID**: Marcos Medina-Tapia **0000-0002-3961-5075**

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Abstract: Gamification has emerged in higher education as an effective pedagogical tool to improve student engagement. This study evaluates the effects of a gamified activity to improve the teaching and learning process by developing solutions for territorial and environmental issues. The activity was carried out during the University Fair Expo USACH 2025 with prospective university students interested in the Civil Engineering in Territory and Environment degree. The activity was developed within a geospatial environment based on a Geographic Information System (GIS) consisting of an interactive simulation where participants piloted a virtual drone to explore sea-flood scenarios in Valparaíso city, Chile, such as a tsunami, identify safe zones, and propose relocation strategies. The results show significant effectiveness, with 93.8% of participants reporting high motivation, and all students showed comprehension of complex geotechnological concepts, such as spatial analysis, layer superposition, and risk management. Moreover, qualitative findings revealed high satisfaction (93.8%) and a clear interest in broadening the thematic focus. Therefore, the study tests gamification as an innovative methodology for teaching geotechnologies, capable of overcoming the limitations of traditional approaches and fostering experiential learning about abstract concepts related to climate change and disaster risk.

Keyword: Gamification

Introduction

Nowadays, higher education continues to face the challenge of maintaining student motivation and engagement. The problem is more complicated if concepts increase its complexity and technology evolves rapidly. This challenge is particularly evident in STEM disciplines such as territorial engineering and geosciences. It is worth noting that theoretical concepts are abstract and difficult to understand the first time you hear them, such as spatial analysis, risk management, and land-use planning. Therefore, teaching them demands innovative approaches that go beyond traditional instruction (Ratinho & Martins, 2023).

One of the main topics to face this challenge is gamification. We understand it as the use of game design principles and mechanics in non-game contexts. This technique has recently gained recognition as an effective pedagogical strategy (Cobos Sanchez et al., 2021; Roa González et al., 2022). In this context, recent studies suggest that integrating elements like points, badges, and leaderboards can enhance both students' intrinsic and extrinsic motivation (Khaldi et al., 2023). These new techniques are consistent with Self-Determination Theory, which explains that when people's needs for autonomy, competence, and relatedness are met, their intrinsic motivation grows naturally (Li et al., 2024).

Another important aspect of this research is the use of geotechnologies. These tools help us to collect, process, analyze, and understand digital information about the territory. Their implementation requires the integration of diverse competencies, including computational, fieldwork, and environmental expertise. Today, they play a crucial role in

managing disaster risks (Tahri et al., 2024). Consequently, teaching in these areas is shifting toward more active and participatory methodologies in which tools such as Geographic Information Systems (GIS), remote sensing, and virtual simulations encourage deeper and more meaningful learning.

Experience-based learning and digital technologies are an interesting combination to design immersive experiences that overcome physical and logistical limitations. These tools such as virtual reality and interactive simulations can help students to understand abstract concepts and engage both their emotions and thinking. A 2024 systematic review shows that these immersive technologies enhance environmental awareness and deepen students' understanding of complex ideas (Ladykova et al., 2024; Tene et al. 2024). The combination of gamification, geotechnologies, and experiential learning could provide a valuable way to face teaching challenges in training future professionals in territorial and environmental management. However, there is still little research that evaluates how these three approaches work together in higher education.

Therefore, this study aims to explore how integration of gamification, geotechnologies, and experiential learning can make teaching and learning more engaging and effective in higher education. The focus is particularly on the training of future professionals in territorial and environmental engineering.

In the following sections, the paper presents the research objective, the method used, the main results, a discussion of the findings, and the conclusions of the research.

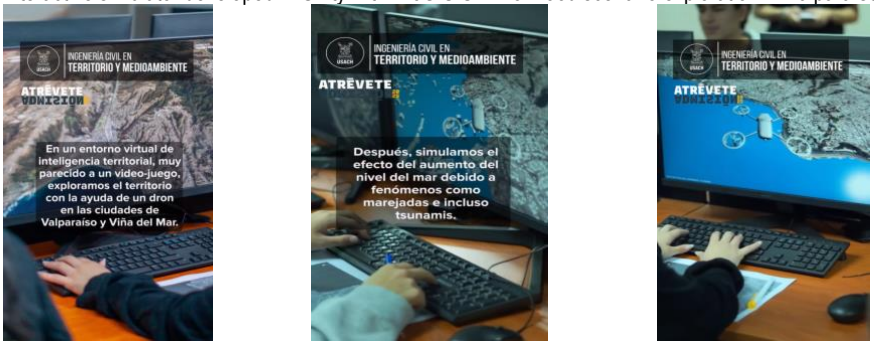
Objective: This study aims to evaluate the effectiveness of a geotechnology-based gamified activity designed to teach concepts of disaster risk management and land-use planning to prospective higher education students, with a specific focus on assessing the levels of motivation generated and the depth of conceptual understanding achieved.

Methods

Research approach

A cross-sectional descriptive study with a mixed-methods approach (quantitative and qualitative) was conducted to evaluate the effectiveness of a gamified pedagogical intervention within the context of a University Fair: Expo USACH 2025. The simulation tool was previously developed by the research authors in the Unity platform using programming techniques and ESRI APIs. The application consists of a drone flying over the city of Valparaíso, Chile, which can be piloted using a computer keyboard, allowing users to activate the visualization of 3D buildings and adjust flood levels (Figure 1).

Figure 1.
Interactive simulator developed in Unity with ArcGIS SDK for flood scenario exploration in Valparaíso, Chile.



Participants

The sample consisted of N=16 secondary school students interested in the Civil Engineering in Territory and Environment program at the University of Santiago, Chile. The participants were attendees of the university fair held on August 25, 2025, who voluntarily registered for the activity.

Implementation of the gamified activity

The gamified activity lasted approximately 25 minutes. Our activity consisted of three sequential phases designed to guide students through the tasks:

1. Theoretical induction (5 minutes): In the first phase, the instructors introduce basic concepts related to climate change, disaster risk, territorial hazard, and vulnerability. These concepts will allow students to carry out the activity of the next step.
2. Gamified simulation (15 minutes): The instructors assigned a mission to the students to solve a territorial problem using the interactive simulator. By piloting a virtual drone, they explored the coast of the city of Valparaíso, Chile, and simulated several flood scenarios such as tsunamis and storm surges. During the simulation, the students identified safe zones and formulated proposals for the relocation of housing and critical infrastructure. To develop their solutions, the students applied principles of spatial analysis and the superposition of georeferenced information layers.
3. Reflective evaluation (5 minutes): Finally, the instructors applied an evaluation instrument to facilitate a group analysis on the learning experience.

Survey instrument

A semi-structured questionnaire with six items was administered to evaluate different aspects of the learning experience. The survey explored the level of motivation generated by the gamified simulation (using a categorical scale) and participants' understanding of the concepts of hazard, vulnerability, and their interrelation (categorical scale). Moreover, it assessed participants' skills to visualize the spatial superposition of information layers (dichotomous scale). Finally, respondents were asked to describe the most positive aspects of the experience, identify areas for improvement, and provide additional comments or recommendations for future iterations of the activity (open-ended questions).

Data collection process

The questionnaire was applied immediately after the gamified activity. It is worth noting that participation was voluntary and anonymous, ensuring the confidentiality of all responses.

Data analysis

We analyzed the quantitative data using descriptive statistics, such as frequencies and percentages. Moreover, qualitative data were analyzed using an inductive thematic approach, considering the frequency of responses and their distribution across categories.

Results

Sample characteristics

The sample consisted of 16 secondary school students who participated in a university fair at the University of Santiago of Chile. The activity lasted approximately 25 minutes and involved a gamified simulation using a virtual drone within the study area corresponding to the coast of Valparaíso, Chile.

Quantitative results

1. On learning motivation: The responses show the exceptional ability of the activity to foster learning motivation. The majority of students (93.8%) reported high levels of motivation, whereas only one student (6.2%) indicated partial motivation. No participants reported a lack of motivation (Table 1).

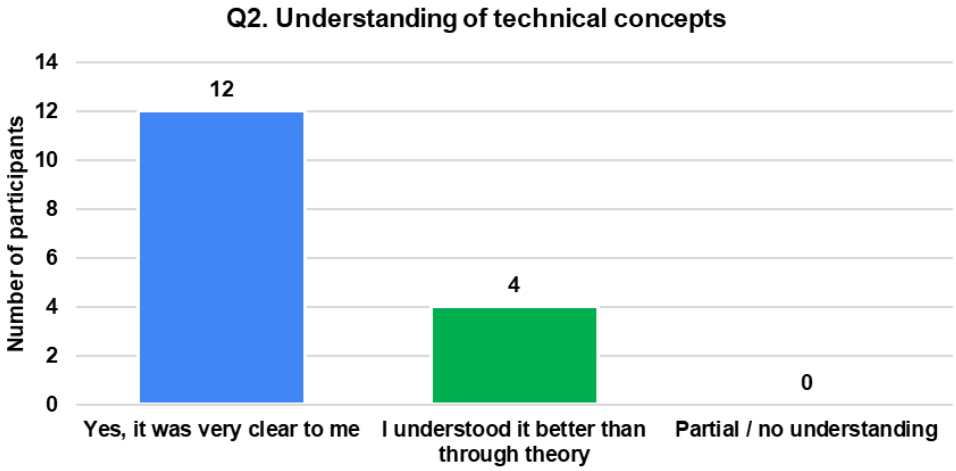
Table 1.
Distribution of Learning Motivation across Variables.

Variable	Response Category	n	%
Q1. Motivation generated by the simulation	Yes	15	93.8
	A little	1	6.2
	No	0	0
Q2. Understanding of technical concepts	Yes, it was very clear to me	12	75.0
	I understood it better than through theory	4	25.0
	Partial / no understanding	0	0
Q3. Visualization of layer superposition	Yes, I was able to visualize it clearly	16	100.0
	I understood it better than through theory	0	0
	Partial / no visualization	0	0
Q4. What did you like most about the activity?	Simulation with the drone.	9	56.0
	The combination of theory and practice.	6	38.0
	Proposing solutions.	1	6.0
Q5. Overall satisfaction	"There was nothing I didn't like"	15	93.8
	The theoretical part.	0	0
	The time allocated to the activity.	0	0
	"The simulation tool"	1	6.2

2. On conceptual understanding of technical concepts: The pedagogical effectiveness reached 100% successful comprehension. Specifically, 12 students (i.e., 75.0%) stated that the concepts were "very clear" to them, while 4 students (i.e., 25.0%) indicated that they "understood them better than through theory." None of the students reported partial or null comprehension (Figure 2).

   All participants were able to clearly visualize the superposition of georeferenced information layers, demonstrating the effectiveness of the virtual drone tool in supporting the understanding of three-dimensional spatial analysis. The elements most valued by students were the virtual drone simulation (56.2%, n = 9), the integration of theory and practice (37.5%, n = 6), and the proposal of solutions (6.2%, n = 1). The level of satisfaction was very high, with 15 students (93.8%) reporting that there was "nothing they disliked" about the experience, while only one student (6.2%) expressed specific dissatisfaction with the proposed simulation tool.

Figure 2.
Students' Conceptual Understanding in the Gamified Activity.



Qualitative analysis

1. On the participation in open comments: Considering the 16 participants, 11 students (i.e., 68.8%) provided open-ended comments, indicating a high level of engagement and reflection on the learning experience.
2. On the thematic categorization. The analysis revealed four main categories:
   - Technical aspects and system performance (63.6%, n = 7): Students identified improvement opportunities regarding system performance optimization and enhancement of the available hardware. Representative comments included: "Just more fluency" and "I really liked it, but it should run more smoothly." The computers need to be upgraded to improve overall system performance.
   - Content expansion (18.2%, n = 2): Students expressed interest in incorporating real historical cases and simulating multiple types of disasters. Some of comments included expressions, such as: "The simulation could show more possible natural disasters" and "I would like it to include an earthquake drill."
   - Satisfaction with the methodology (9.1%, n = 1): Students expressed positive evaluations of the proposed didactic approach, such as: "I loved this activity; it's very didactic."
   - Additional historical content (9.1%, n = 1): One student suggested "including a bit more about events that actually happened."

Synthesis of pedagogical effectiveness

The learning indicators revealed exceptionally high levels of student motivation, with 93.8% of participants reporting high motivation. Conceptual understanding was also outstanding, as 100% of the students demonstrated successful comprehension of the key concepts. Similarly, 100% of participants showed effective spatial visualization skills, reflecting a clear understanding of the superposition of information layers. Overall satisfaction was notably high as well, with 93.8% of respondents indicating no negative aspects of the experience. Finally, 68.8% of participants contributed reflective comments, showing how actively involved they were during the activity.

Discussion

Validation of pedagogical effectiveness

The results allow us to confirm the initial hypothesis regarding the effectiveness of gamification in teaching geotechnologies applied to socio-environmental risk management. The quantitative indicators of exceptional motivation (93.8%) and complete conceptual understanding (100%) are directly aligned with the extensive empirical evidence demonstrating the capacity of gamification to enhance student engagement through the fulfillment of fundamental psychological needs for autonomy, competence, and social relatedness (Li et al., 2024).

The fact that a quarter of the students (25.0%) reported understanding the concepts "better than through theory" suggests a clear pedagogical advantage of gamification over traditional expository methods. This finding is consistent with previous studies showing that experiential methodologies are especially helpful for understanding complex systems (Janeras et al., 2022; Limantara et al., 2022).

Methodological synergy

The success of the intervention lies in its hybrid and integrative design, which combines three validated streams of educational innovation: gamification as a motivational driver, geotechnologies as tools for spatial analysis, and experiential learning as a knowledge-construction methodology. The activity functioned as a carefully structured experiential learning experience, allowing students to "do" rather than merely "listen," which is consistently highlighted in the literature as a superior approach for understanding complex territorial dynamics.

Understanding of geotechnological concepts

The 100% effectiveness achieved in the comprehension of technical concepts such as hazard, vulnerability, spatial analysis, and layer superposition can be explained by the immersive nature of the simulation. When students faced real territorial management problems and used digital tools to analyze them, they built meaningful knowledge instead of just memorizing abstract concepts.

Student demand for new applications

The qualitative comments reveal not only satisfaction but also an active demand for thematic expansion toward other types of disasters (e.g., earthquakes, pollution) and real historical cases. This demand validates the scalability potential of the methodology and suggests that students perceive genuine educational value in the gamified approach.

Identified limitations

Students primarily identified technical rather than pedagogical limitations, mainly related to system performance and fluency. This indicates that the instructional design was appropriate but requires technological optimization. Such constructive feedback demonstrates the students' commitment to improving the tool.

Comparison with educational standards

The results far exceed traditional educational standards. The 93.8% motivation rate compares favorably with studies reporting significantly lower motivation levels in traditional lecture-based methodologies. The 100% rate of conceptual understanding is exceptional when compared with typical comprehension levels in higher education, which rarely reach such values in immediate post-activity assessments.

Implications for educational practice

The findings support the curricular integration of gamification within engineering and geoscience programs. The expressed student demand justifies investment in technical system improvements and suggests strong potential for implementation across diverse educational contexts. The methodology demonstrates particular value for teaching concepts that require spatial visualization and the understanding of complex systems.

Conclusions

The results offer significant empirical evidence of the pedagogical effectiveness of gamification. The results show that combining gamification with geospatial tools and experiential learning was highly effective. It helped increase student motivation and strengthen their understanding of key concepts. The study shows significant results in teaching geotechnologies applied to socio-environmental risk management. Our results show that hybrid educational designs can effectively promote active and meaningful learning experiences based on spatial understanding in higher education. Thus, our findings confirm that gamification can reduce the learning gap between abstract theoretical content and applied spatial reasoning.

Students' feedback showed high satisfaction with the proposed activity and a clear interest in expanding it to include new topics and technical improvements. The main limitations were technical, not pedagogical, indicating that the instructional design worked well overall but could be improved with enhanced system performance. This constructive feedback shows how engaged students were and how willing they were to help improve the learning experience. It is worth noting the importance of involving them in the continuous development of educational tools.

Future work should aim to optimize the system's technical performance and extend the simulation to other territorial and environmental areas, such as urban mobility and transportation. Overall, the study shows that gamified geotechnological environments can be transformative teaching tools. These tools help students develop the analytical, spatial, and problem-solving skills needed for sustainable territorial and environmental management.

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