

Article

Raising Awareness of Climate Heritage Resilience and Vulnerability by Playing Serious Video Games

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Abstract: Contemporary climate change affects not only human beings and natural ecosystems but tangible cultural heritage, too. Understanding and appreciating climate change’s influence on built cultural heritage involves raising awareness of vulnerability and resilience issues. Hence, educators need to develop integrated approaches to teaching the protection and preservation of architectural heritage from climate change, including the creation of educational resources, including serious video games, to teach climate resilience and vulnerability. In this context, the authors developed two 3D maze video games—“Let Us Save Venice” and the Vulnerability game—focused on engaging students and raising awareness of climate heritage issues. The article discusses the results from the experimental validation of the Vulnerability game and tries to answer how game design enhanced by using the revised Bloom taxonomy and active collaboration with domain specialists can improve learning outcomes, learnability factors, and game experience. The findings suggest that the maze games can effectively supplement traditional teaching approaches in raising awareness and teaching climate resilience in cultural heritage contexts.



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Keywords: climate change; heritage vulnerability; serious video games; raising awareness

1. Introduction

Climate change effects on the territory encompass the accentuation of weather phenomena and their consequences, such as flooding, hydrogeological instability, soil and coastal erosion, droughts, fires, and sea level rise [1,2]. Besides the extreme events, climate change also comprises trends, like the gradual increase in mean temperatures, whose effects are less immediate but equally relevant as they can involve broad territories. All these occurrences, whether standalone or in combination, influence the social and ecological balances, as they threaten human and animal life, contributing to the alteration and degradation of ecosystems and affecting human settlements and activities. It entails, among other things, significant consequences on cultural heritage [3,4].

Understanding the effects of climate change on human life and assets, including cultural heritage, involves introducing concepts like vulnerability, resilience, impact, adaptation, etc. In particular, considering vulnerability is critical for identifying strategies to foster the resilience and adaptation of territories in general and cultural heritage [5]. In the

field of climate studies, vulnerability is defined as “the propensity or predisposition to be adversely affected”, and it “encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” [6,7]. However, vulnerability assessment has evolved, including scientific/physical and human/social framing [1,8]. Furthermore, some authors recognize that vulnerability should not be considered the opposite of resilience [9], as the two terms are in a continuum of relationships [10] of “resiliency vulnerability” in the sense that only the experience of a vulnerability can trigger a resilience reaction.

The general framework defined in the e-CREHA (Education for Climate Resilient European Heritage Architecture) Erasmus+ project highlighted the need and significance of raising awareness of the climate change effects on architectural heritage through an integrated approach, ranging from the detailed scale of the degradation of building materials to the broad scale of regional planning (<https://www.ecreha.org/> (accessed on 18 December 2024)). The approach applied novel maze video games about cultural heritage aiming to introduce a younger generation to climate heritage issues using multimedia interactive content [11]. Thus, students and young people became familiar with the topics concerning vulnerability, adaptability, and preservation of cultural heritage in a way adequate to their perceptions. The authors supposed that raising awareness of cultural heritage issues can be achieved, along with other actions, with the video game technology that is a usual part of the daily habits of digital natives. Hence, e-CREHA video games were applied to assist the acquisition of knowledge and skills enhanced through ICT-based technologies [12] and raise awareness in the context of cultural heritage. For the first e-CREHA workshop held in September 2021 at the Technical University of Eindhoven (The Netherlands), a maze video game for climate heritage resilience named “Let Us Save Venice” (further referred to as the Resilience game) was created and successfully validated, proving its high learnability and engagement [13]. The second workshop, held in September 2022 at the University of Molise (Italy), also involved a practical experiment by playing a maze video game dedicated to climate heritage vulnerability (hereafter referred to as the Vulnerability game). For designing this game, the authors used content co-creation based on templates. The revised Bloom’s taxonomy [14] was applied to structure the learning content and select and design the mini-games embedded into the maze halls. This approach ensured that the educational objectives were aligned with different cognitive levels, starting from basic knowledge remembering and involving higher-order thinking skills, e.g., analysis, synthesis, and evaluation. The game design addresses these cognitive levels and enables a structured sequence of learning activities, allowing players to build on their knowledge and skills incrementally. Applying the revised Bloom’s taxonomy to the educational game design allows each mini-game to be crafted to target specific cognitive processes. Further, the game integrates various interactive elements and challenges to foster an engaging learning environment adaptable to the diverse academic needs of players. The Vulnerability game was expected to enhance player engagement and effectively contribute to students’ understanding of climate heritage vulnerability and resilience thanks to combining theoretical frameworks with practical game design principles.

2. Research Aim

The current article presents the design and construction of the Vulnerability game—an educational maze game about climate heritage vulnerability, and its assessment through a practical experiment with a community of participants as bachelor, master, and Ph.D. students from the e-CREHA partners’ universities having diverse ages and specialties. The results are compared with those obtained from evaluating the “Let Us Save Venice” maze game about climate heritage resilience [13]. Both the Vulnerability game and the Resilience

game are focused on climate heritage issues and have similar creation processes. However, the Vulnerability game benefits from a game design enhanced by:

1. Using the revised Bloom taxonomy for selecting mini-games for the maze;
2. Involving expert opinions on climate heritage issues for the didactic content integrated into the game.

Hence, the research goal is to evaluate the expected contributions of the enhanced game design of the Vulnerability game in terms of better learnability and improved gaming experience, which raises awareness of the considered topics. In this context, the study seeks answers to the following research questions:

RQ1. How do the results from the practical evaluation of the developed serious maze games about climate heritage resilience and vulnerability compare regarding game experience and learnability?

RQ2. How does the improved content design using the revised Bloom taxonomy and expert opinions on climate heritage issues (applied to the Vulnerability game creation) contribute to the game experience and learnability compared to the Resilience game?

RQ3. Are there any interrelations between the attributes of learnability and the factors of game experience?

RQ4. Could age, gender, and amount of video game playing influence the learnability attributes and factors of game experience?

3. Related Works

Nowadays, architectural heritage is understood extensively as Built Cultural Heritage (BCH), composed of the (immovable) archeological, architectural, and landscape heritage, consistent with the identification of cultural heritage with monuments, groups of buildings, and sites by UNESCO [15]. It includes the cultural landscapes intended as sites resulting from the “combined works of nature and man” [16]. Such an approach stresses the importance of continuing human activity to preserve BCH by reproducing it [17] and the ability of (local) human societies to develop effective ways to adapt to the changing environmental contexts [18,19]. In this sense, we can recognize that heritage communities, consisting of “people who value specific aspects of cultural heritage which they wish, within the framework of public action, to sustain and transmit to future generations” [20], have the potential to contribute to the “resiliency vulnerability” [10] of the landscapes, providing them with the long-lasting maintenance needed to maintain hydrological and ecosystem balances and to prevent the adverse effects of climate change.

Two crucial steps are necessary to effectively address cultural heritage’s vulnerability to climate change. On one side, they are related to developing and implementing tailored climate adaptation strategies for high-risk heritage sites [21], and on the other side—raising public awareness about the threats that climate change poses to fragile and irreplaceable cultural resources [22]. The e-CREHA project aims to strengthen the integration of climate heritage concepts, such as resilience, vulnerability, impacts, and adaptation, into architectural education, spanning academic curricula and professional training. Thus, the e-CREHA initiative sought to establish a robust educational foundation in the architectural field, focused on building climate resilience for invaluable heritage assets. Striving to achieve this goal, the project team has developed e-learning courses featuring modules, lectures, quizzes, assignments, and serious video games.

Serious video games were chosen as an innovative learning resource with an interactive and engaging nature. Serious games have a primary objective different than entertainment [23,24]. The characteristics essential to such games include integrated activities aimed at educating and training, which support knowledge or skills acquisition [25]. In the cultural heritage area, they combine both the educational and enjoyment potential

of games while providing information about and engaging users with the complex issues in this field [26,27]. They can raise awareness of the context and problems, technological solutions, and efficient approaches to cultural heritage preservation [28–30].

Different genres and types of video games that cover the theme of cultural heritage exist [31]. Virtual world games often provide immersive experiences and enable appreciation of the related multimedia information content. Usually, such games allow users to access and explore some cultural heritage object or site remotely in a personalized way while enabling virtual users' avatars to "touch and manipulate" artifacts without any risk. In addition, these serious games often include challenges and missions, which allow active learning experiences [32]. However, there are a lot of simple video games about immovable cultural heritage that only give basic information and allow limited interactions. Most serious games and applications in cultural heritage areas aim to present intriguing information, foster the dissemination of knowledge, and extend traditional ways of learning [33,34].

The challenges of making a video game with environmental themes regarding design, development, and publishing to raise awareness about climate change issues are summarized in [35]. The Climate Heritage Game project [36] aims to create such games as an immersive training tool for engaging students with heritage preservation and climate change mitigation topics. e-CREHA is another project applying educational video games to raise awareness of the climate issues regarding built heritage. In the scope of e-CREHA, a Resilience game (named "Let Us Save Venice") was created by automatic maze generation through the APOGEE platform [13,37]. The APOGEE platform (built as a plugin to the Unity editor) was applied to generate all the 3D maze video games for the e-CREHA project using formal definitions in Extensible Markup Language (XML) of the maze structure and mini-games embedded in the maze halls [38]. The XML descriptions define the structure and interior of the maze, as well as the learning multimedia content, presentation, and settings of educational tasks represented by learning objects and educational mini-games.

4. Materials and Methods

4.1. Design Methodologies

The educational video game about climate heritage vulnerability was the second maze game created as a part of the e-CREHA Erasmus+ project [39]. Both the Resilience and Vulnerability games represent 3D educational mazes enriched with various 2D and 3D mini-games that encompass diverse educational tasks [38]. The maze games were designed following the user-centered methodology outlined in [40]. Their game design is based on a formal XML description of the educational maze containing various mini-games that enable automatic game generation using the APOGEE platform [37]. While the learning design of the Resilience game was based on a selection of didactic content from documents suggested by domain specialists, the Vulnerability game design included a closer collaboration between game designers and various specialists by exchanging versions of the XML maze descriptions using shared templates. All authors contributed incrementally and iteratively to create these descriptions and the multimedia resources, which appeared similar for both games, as shown in Table 1.

Especially for designing the learning objects and the mini-games for the Vulnerability game, the revised Bloom's Taxonomy of learning outcomes was applied [14]. The revised taxonomy builds on the original Bloom's Taxonomy from 1956 [41], which examined cognitive skills and learning behavior. The updated Bloom's taxonomy includes six conceptually different dimensions, representing levels of cognitive learning that are (from bottom to top): remembering, understanding, applying, analyzing, evaluating, and creating. Similar to the work of Sherry and Pacheco [42], who related Bloom's educational objectives with

applied game genres, the authors related the levels of cognitive learning to the mini-games existing on the APOGEE platform [38].

Table 1. Design comparison of the Resilience and Vulnerability games.

Activity	Resilience Game	Vulnerability Game
Game design	User-centered design methodology; circular maze with 5 halls	User-centered maze design methodology; circular maze with 5 halls
Learning content design	Selection of content from documents suggested by domain specialists; 38 multi-slide learning boards	Active collaboration between game designers and domain specialists using shared templates; 39 multi-slide learning boards
Learning objects and mini-games design	No framework was applied; 5 types of mini-games with 8 game instances	The revised Bloom’s Taxonomy of learning outcomes was applied; 6 types of mini-games with 9 game instances
Formal description design	XML description of 771 lines used for automatic maze generation by the APOGEE platform	XML description of 746 lines used for automatic maze generation by the APOGEE platform
Multimedia design	82 images and 5 audio resources	75 images and 5 audio resources
Distribution design	An online video game accessible through a Web page (limited to workshop participants)	An online video game accessible through a Web page (limited to workshop participants)

Figure 1 illustrates the relationships between dimensions of the revised Bloom taxonomy and the maze mini-games, which include learning boards inside the maze halls that present information or didactic tasks. Some of the mini-games have two versions, such as “Rolling balls”, which can involve rolling a ball to a specific object or location on the map, and “Memory”, which may require matching image to image (Img2Img) or image to text (Img2Txt). Table 2 explains the application of the revised Bloom taxonomy in the Vulnerability game design. It offers a non-formal definition of each taxonomy dimension and explanations of their application in the maze game design.

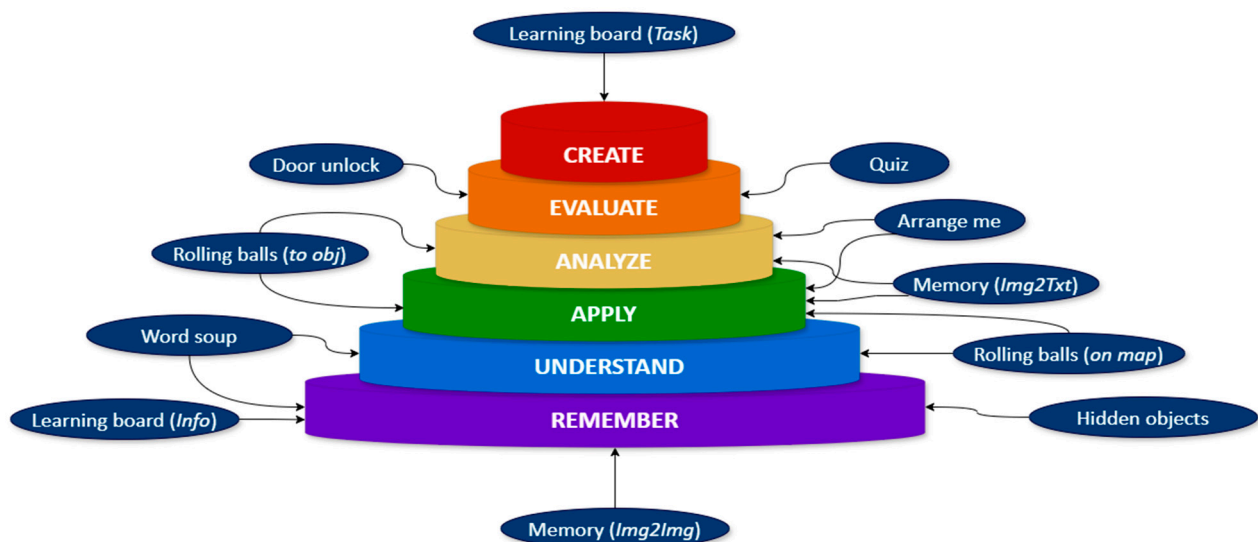


Figure 1. Relationships between dimensions of the revised Bloom taxonomy and the maze mini-games.

Table 2. Application of the revised Bloom taxonomy in Vulnerability game design.

Taxonomy Dimension	Dimension Definition	Application in the Maze Game
Create	Produce new, original work	Read the instructions on the learning boards about a specific task (e.g., read an additional learning resource) or a mini-game in the maze hall.
Evaluation	Justify a standpoint or decision	Select the correct answer(s) in the quiz game with various difficulty levels or answer questions to unlock the next hall.
Analyze	Draw connections among ideas	Arrange images in a time sequence or specific order; Compare images to textual descriptions to find the right match between image and text; Roll a ball to the correct 3D object.
Apply	Use the information in a new situation	Roll a ball to a 3D object with new contextual information; Arrange images according to new contextual descriptions; Mapping images to a textual description; Locate the correct position on a map and roll a ball with an appropriate textual description.
Understand	Explain ideas or concepts	Locate the correct position on a map and roll a ball with an appropriate textual description; Identify terms on the character table corresponding to specific definitions provided in the help.
Remember	Recall facts and basic concepts	Remember facts and concepts given at information learning boards or hidden 3D objects with metadata; Memorize them through memory game matching images; Remember terms as identify them on the character table.

4.2. Game Implementation

The Resilience and Vulnerability educational games represent 3D mazes enriched with 2D and 3D mini-games containing various didactic tasks [38]. The Vulnerability game was created one year after the Resilience game, and an enhanced version of the custom maze game platform was applied [37]. In this version, the authors reflected all the remarks and proposals for improvement of the game interface, such as the maze navigation method, titles of maze halls, multi-slide learning boards, pause of the music reproduction, mute mode, hidden objects with metadata visible after finding the object, a multi-level quiz with the threshold for passing each level, contextual help, and many others. The didactic content for both the learning boards and mini-games, elaborated by the team of the University of Molise, represents cases of climate vulnerability of immovable cultural heritage from Molise Region, Italy. The types of mini-games presented in the maze halls were selected by following the revised Bloom taxonomy as explained above. Similar to the Resilience game, the maze had a circle topology including five halls: Introduction, The Context, The Problem, The Solution, and The Future [13]. These maze halls are interconnected by locked doors that the accurate answer to a didactic question can unlock. The game starts at an Introduction hall, where the game's objectives, the maze structure, and the playing process are presented. By giving correct answers to the door-unlocking questions, the player moves to the final hall. The mini-games at the maze halls may be mandatory or optional for the player. The game goals are to reach the final hall of the maze, find all the hidden (semitransparent) objects, and check their descriptions. To achieve these goals, the player has to read the texts on the learning boards and play all the mandatory mini-games. When the players find all the hidden objects, they might restart the game or continue playing the optional mini-games. Figure 2 presents screenshots of the gameplay of the mini-games.



(a)



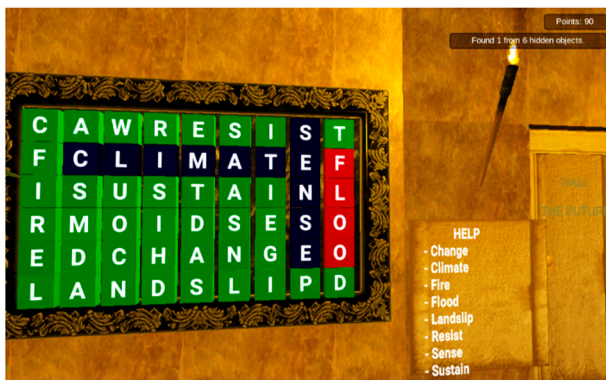
(b)



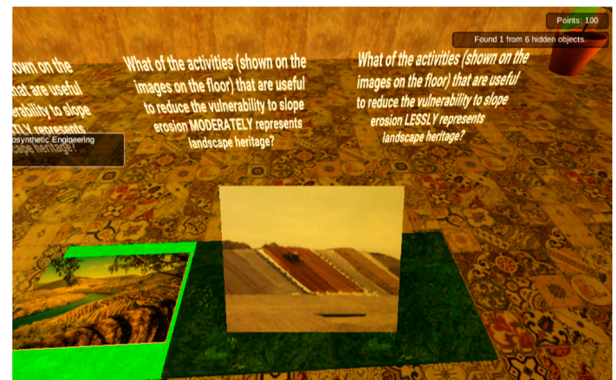
(c)



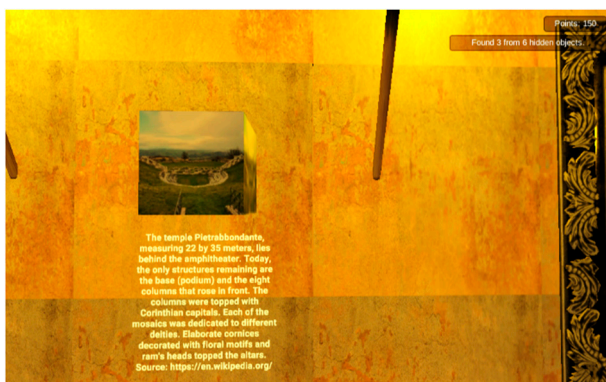
(d)



(e)



(f)



(g)



(h)

Figure 2. Screenshots of the gameplay: (a) a view of the Introduction hall; (b) rolling balls to positions on a map; (c) matching images to texts in the Memory game; (d) answering a door question; (e) finding words in a Word soup 2D game; (f) arranging images according to their description; (g) a found hidden object with its description; (h) first level of a quiz.

The XML document prepared for the Vulnerability game contained a detailed description of all the halls with their doors, learning boards, mini-games, names of the images and the music files, and details about the environment. The comprehensive XML document and the game's graphics and audio resources were provided to a custom-developed plugin installed in the Unity 3D editor [37], which automatically generates the entire 3D maze in Unity. Next, after some additional arrangements, the game was built as an online application and deployed on a project's Web server.

4.3. Evaluation Methodology

The Vulnerability game was specially designed to be integrated into the activities of the e-CREHA student workshop "Climate Impacts and Heritage Vulnerabilities" hosted by the University of Molise, Italy, in September 2022. The ISP has been conceived as a workshop for Master's students in Architecture, Civil Engineering, and Management of Tourism and Cultural Heritage, encompassing lectures, fieldwork, and studio work. The ISP focused on the development, by the students, of design scenarios regarding four case study areas, aimed at defining proposals to reduce the vulnerability of the BCH to the effects of climate change [43], supporting the creation of Climate-Resilient Self-Sustainable Development (CRSSD) paths [44].

The experimental validation of the vulnerability video game was held during the workshop after familiarizing the participants with the topic. All the workshop participants (N = 22) were either Bachelor, Master, or PhD students from the e-CREHA partners' organizations, i.e., from the University of Molise (Italy), TOBB University of Economics and Technology (Türkiye), Eindhoven University of Technology (the Netherlands), Sofia University (Bulgaria), Institut National Des Sciences Appliquees de Strasbourg (France), and some students from Poland. All the participants took several lectures about climate change's impact on cultural heritage. There was a field trip to introduce students to the vulnerability of four different cultural heritage sites. Next, students started studio work on group projects and proceeded with the Vulnerability game-playing session.

The game evaluation process follows the steps in Figure 3. Before the game trial and assessment, the students were introduced to the educational video maze games and, mainly, to the climate heritage vulnerability game through a short presentation. Next, the objectives of the experiment and the game-playing rules were presented. Then, students play the game online for about one hour.

When completing the game, all the participants fill out an informed consent form integrated with an online survey anonymously exploring learnability and gaming experience. The first part of the survey gathers information about students' profile features (age, gender, and game-playing custom). The second part explores the attributes of learnability and factors of game experience through a concise but comprehensive questionnaire containing only 13 items, thus not boring the students with many questions [13]. First, the six attributes of learnability are examined by summarizing the original items for each attribute as suggested in [45] in one general item for shortening the original questionnaire. Next, the seven factors of game experience are explored by a shortened version of GEQ [46], where for each factor, we asked one question integrating the original items for that factor. The answers apply a five-point Likert scale (from 1—strongly disagree to 5—strongly agree). The last part of the survey gathers the specific game-playing results that are numerical indicators for the game's playability and learnability. These include the total playing time, the final score at the playing session, and the number of hidden objects found, i.e., indicators of the overall user interest, engagement, and attitude towards the game. The experimental session ends with several semi-structured interviews and a discussion on students' appreciation of the vulnerability game.

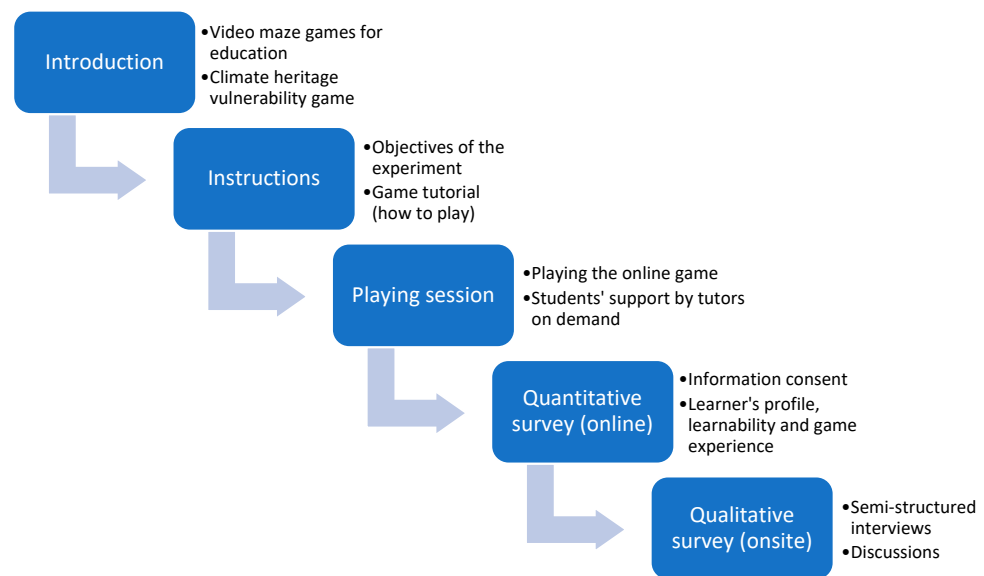


Figure 3. The game evaluation process.

5. Results

5.1. Player Profiles

The Vulnerability game was played and evaluated by all the workshop participants at the premises of the University of Molise, Italy. In total, 22 students ($N = 22$) aged from 18 up to 31 years took part in this pilot game evaluation. Their mean age was $M = 24.86364$, with a standard deviation of $SD = 3.84578$, which is somewhat similar to the mean age ($M = 25.20385$, $SD = 6.48147$) of the participants in the survey about the Resilience game “Let Us Save Venice” ($N = 24$). Six of them were males, and 16 were females. Figure 4 shows (in percentages) the reported weekly amount of playing educational video games and, on the other hand, video games of all types. Most students reported rarely playing video games for either fun or learning. About 37% of the respondents disclosed playing any video game for more than one hour per week, while less than 4% declared playing games for learning between one and ten hours weekly. No students reported playing video games for learning more than 10 h per week. Thus, the players’ profiles look very similar to that of the Resilience game study [13].

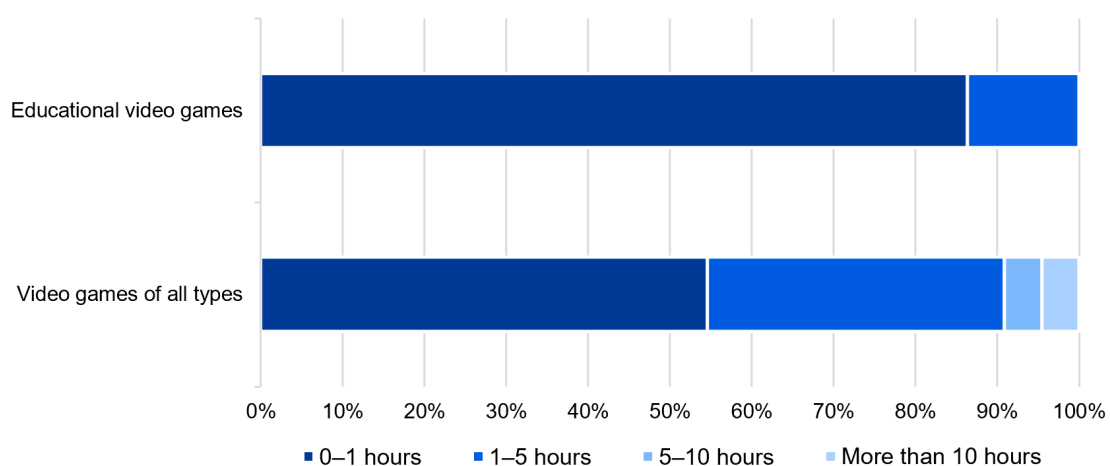


Figure 4. Reported weekly amount of playing video games.

5.2. Game Validation

5.2.1. Evaluation of Game Learnability

The participants in the Vulnerability game session ($N = 22$) played the game between 14 and 65 min, with an average playing time of $M = 27.04545$ min, $SD = 10.45388$, $SE = 2.22877$. Thus, this game was played longer than the Resilience game, where the mean playing time was $M = 23.58247$ min. The players were not asked to play the optional mini-games or find all hidden objects, which gave rise to different playing times. They achieved playing scores between 160 and 700 points for solving the didactic tasks in the mini-games embedded into the maze, with the mean score $M = 440.95455$ points ($SD = 158.82080$, $SE = 33.86071$), i.e., 62.994% of the maximal score, while for the Resilience game, the mean score was 50.028% of the possible maximum. The average number of found hidden objects was $M = 5.22727$ ($SD = 1.26986$, $SE = 0.27074$) or 87.121% of the maximum, while for the Resilience game, it was about 75% of the possible maximum. The playing outcomes (playing time, score, and found hidden objects) for both the games represent pairs of independent samples of continuous data having different variances; hence, the authors conducted the Mann–Whitney–Wilcoxon test and proved higher playing outcomes achieved in playing the Vulnerability game at 95% confidence level ($p < 0.05$).

To measure the strength and direction of linear relationships between pairs of continuous variables, tests for finding bivariate Pearson correlations (r) were conducted. By checking the t -scores for the Pearson correlation r for N observations using the formula $t = r\sqrt{(N - 2)/(\sqrt{1 - r^2})}$, the authors proved no statistically significant correlations between playing outcomes and age, gender, and playing time. On the other hand, medium correlations were found between the playing time and the game score ($r = 0.51029$, significant at $p < 0.05$), the playing time and the quiz score ($r = 0.53939$, $p < 0.01$), and the game score and the number of found hidden objects ($r = 0.38792$, $p < 0.01$). An average correlation was found between the scores for the game and the quiz ($r = 0.43323$, $p < 0.05$), indicating that the total number of points depends heavily on the quiz score.

As shown in Figure 5 (using a five-point Likert scale), all six learnability attributes are appreciated highly for the Resilience and Vulnerability games. After proving their normal distribution and similar variances, the calculated unpaired T -tests revealed statistically significant improvements at $p < 0.05$ with a medium effect size (Cohen's $d \approx 0.3$) only for Ease of Learning and Informative feedback, reported for the Vulnerability maze game (RQ1, RQ2), given in bold in Table 3. Next, Table 4 presents Pearson correlations among the learnability attributes (RQ3), where the statistically significant correlations are shown in bold ($p < 0.05$). Predictability and Informative feedback correlate with Ease of Learning, Familiarity, and Consistency with medium correlations.

Table 3. Metrics of the six attributes of learnability for the Resilience and Vulnerability games.

Attribute	Ease of Learning	Familiarity	Consistency	Predictability	Informative Feedback	Error Handling
Metrics						
t -test (p -value)	0.03926	0.18284	0.34356	0.36859	0.04365	0.17774
ΔM	0.50974	0.19805	0.00325	−0.22078	0.39935	0.37987
Pooled SD	1.76831	1.45209	1.57259	1.29413	1.34415	1.39162
Cohen's d	0.28826	0.13639	0.00206	−0.17060	0.29710	0.27297

For answering RQ4, the six attributes of learnability were applied as multiple ordinary dependent variables in ordinal logistic regression. The independent variables were age, gender, and the amount of time spent playing video games. All the created ordinal logistic regression models had t -values of the regression coefficients less than the critical threshold of 1.96 (at a 5% significance level) and low values for R^2 and adjusted R^2 metrics

(representing the proportion of the variance for a dependent variable that is explained by independent variables in the regression model), proving that factors such as age (measured as a single number provided by the participant), gender, and amount of video game playing do not influence the learnability attributes.

Table 4. Pearson correlations between the six attributes of learnability.

Pearson r \ Attribute	Ease of Learning	Familiarity	Consistency	Predictability	Informative Feedback	Error Handling
Ease of Learning	1					
Familiarity	0.38711	1				
Consistency	0.36060	0.21252	1			
Predictability	* 0.46427	* 0.50374	0.17867	1		
Informative Feedback	* 0.43204	0.23372	* 0.44618	0.41114	1	
Error Handling	−0.08573	0.17926	−0.08025	0.07638	−0.10367	1

* $p < 0.05$.

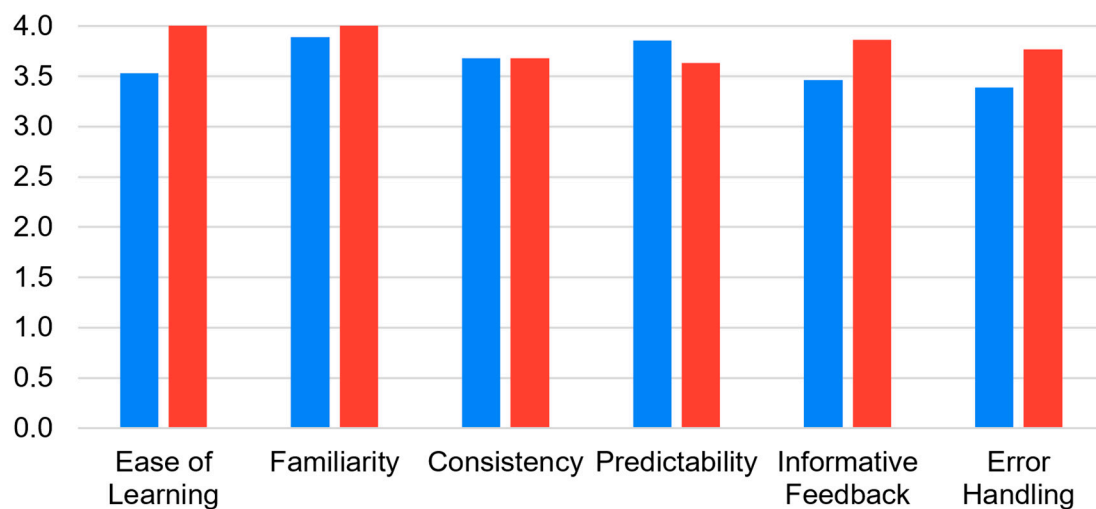


Figure 5. Comparison of survey results for the attributes of learnability for the Resilience (Blue) and Vulnerability (Red) maze games.

5.2.2. Game Experience Gained in the Mini-Games

The seven factors of the game experience described in [38]—Flow, Challenge, Competence, Positive Affect, Negative Affect, Immersion, and Tension were assessed using the same authors' questionnaire as in [13]. The factors assessment was calculated as mean values of the reported assessments using a five-level Likert scale for all the mini-games embedded into the Vulnerability maze game, namely “Door unlock” (asking a question for unlocking the door), “Rolling balls” (to objects or to map locations), “Hidden objects”, “Word soup”, “Memory”, “Arrange me”, and “Quiz” (Figure 6).

The highest results were observed for four factors: Positive Affect—for “Quiz” mini-game $M = 4.22727$, $SD = 0.86914$, $SE = 0.18530$), Competence—for “Hidden objects” $M = 4.09091$, $SD = 0.75018$, $SE = 0.15994$), Immersion—for “Quiz” $M = 3.95455$, $SD = 1.13294$, $SE = 0.24154$), and Flow—for “Memory” $M = 3.77273$, $SD = 1.10978$, $SE = 0.23660$. Thus, the high values of Positive Affect, Immersion, Competence, and Flow testify to the positive appreciation of the mini-games located in the maze. On the other hand, the negative experience factors received values below neutral for all of the mini-games—the Tension was reported with the highest value for “Rolling balls” ($M = 2.54545$, $SD = 1.29935$, $SE = 0.27702$), and Negative Affect received the highest values for the same mini-game ($M = 2.45455$, $SD = 1.18431$, and $SE = 0.25250$).

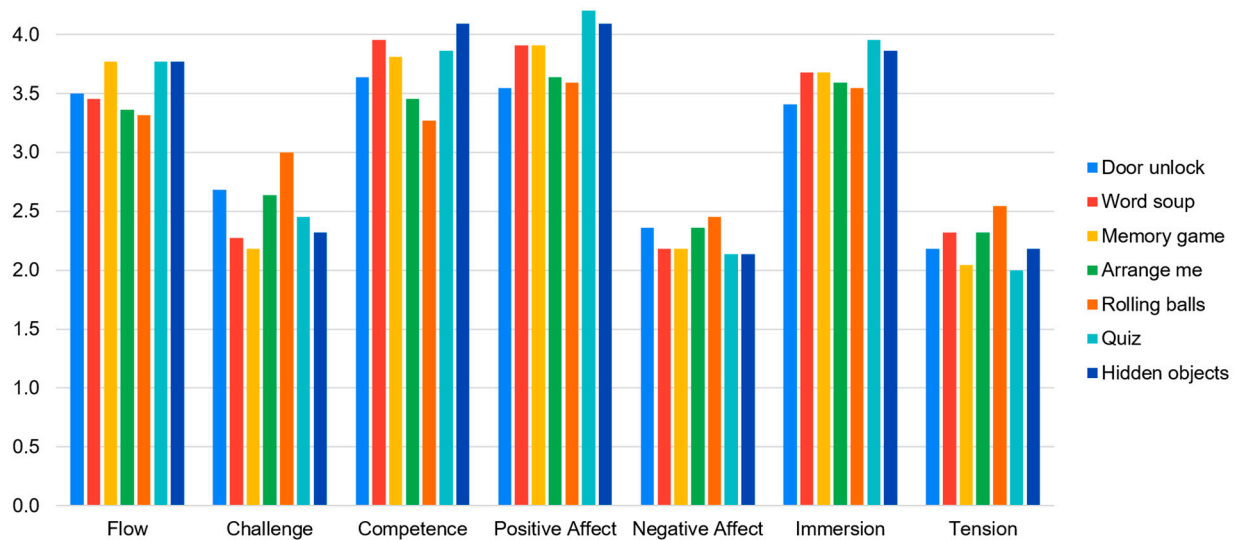


Figure 6. Mean values of the game experience factors for all mini-games included in the Vulnerability maze game.

Figure 7 compares the results for the game experience factors for the Resilience and Vulnerability maze games, while Table 5 presents the statistical metrics for this comparison (RQ1, RQ2). For the Vulnerability game, Flow and Positive Affect received improved values with a moderate effect size (Cohen's $d > 0.25$); however, the Challenge and Negative Affect decreased moderately (Cohen's $d < -0.27$)—all significant at $p < 0.05$. Next, Table 6 provides Pearson correlations among the game experience factors for the Vulnerability game (RQ3), with statistically significant correlations (in bold) and a legend of the level of significance given below the table. The correlations in bold appear much stronger and more substantial than those found for the Resilience game [13].

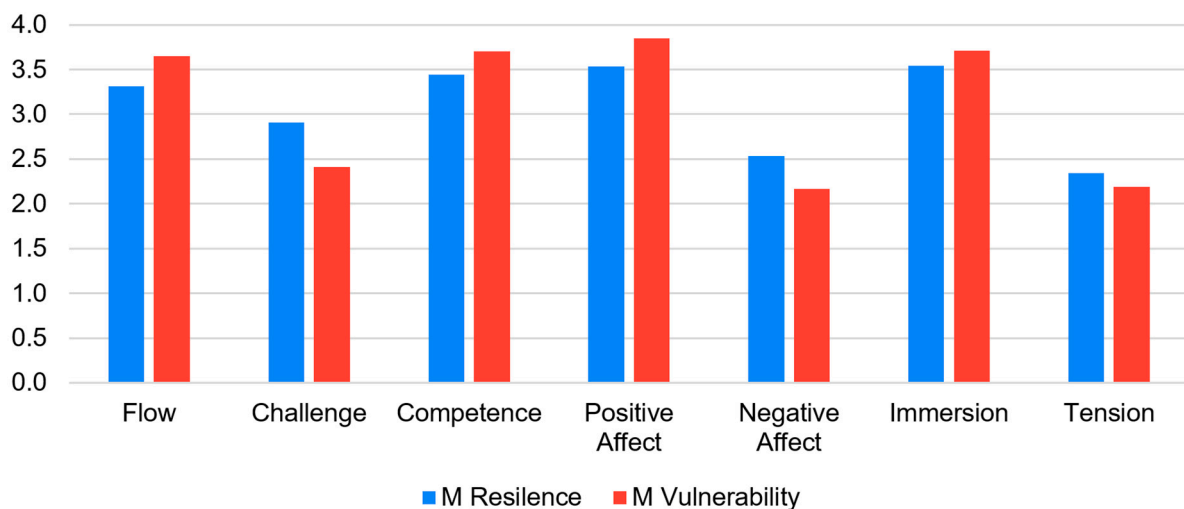


Figure 7. Comparison of survey results for the factors of game experience for the Resilience and Vulnerability maze games.

Finally, the authors investigated the influence of age, gender, and the amount of playing video games (used as independent variables) over each of the seven components of game experience calculated as a set of mean values for all the mini-games reported by the participants (RQ4). For the continuous dependent variables representing the seven components of game experience, the assumptions of multivariate analysis of variance (MANOVA) for observations' independence, homogeneity of variances, normality, and

linearity were confirmed. The analysis revealed several factors with a large effect size over some of the experience components, having a large effect size ($R^2 > 0.3$):

- The interaction between age and educational game playing is a factor for the variance of flow with $R^2 = 0.41505$ significant at $p < 0.01$;
- The interaction between age and educational gameplay is a factor for the variance of competence with $R^2 = 0.43594$ significant at $p < 0.05$;
- The interaction between age, gender, and educational game playing is a factor for the variance of positive affect with $R^2 = 0.50534$ significant at $p < 0.05$;
- The interaction between gender, total game playing, and educational game playing is a factor for Tension variance with $R^2 = 0.31942$, significant at $p < 0.05$.

Table 5. Metrics of the seven factors of game experience for the Resilience and Vulnerability maze games.

Factors Metrics	Flow	Challenge	Competence	Positive Affect	Negative Affect	Immersion	Tension
<i>t</i> -test (<i>p</i> -value)	0.04895	0.03857	0.10035	0.04413	0.04008	0.16785	0.18849
ΔM	0.33731	−0.49816	0.26540	0.31014	−0.35881	0.17179	−0.15256
Pooled SD	1.22843	1.34305	1.22164	1.19657	1.31819	1.25944	1.19877
Cohen's <i>d</i>	0.27459	−0.37092	0.21725	0.25919	−0.27220	0.13640	−0.12726

Table 6. Pearson correlations between the seven factors of game experience.

Factors Pearson <i>r</i>	Flow	Challenge	Competence	Positive Affect	Negative Affect	Immersion	Tension
Flow	1						
Challenge	0.21886	1					
Competence	** 0.83690	0.26321	1				
Positive Affect	** 0.82530	0.19795	** 0.88843	1			
Negative Affect	−0.04117	* 0.61540	0.11159	−0.00916	1		
Immersion	** 0.88527	0.15200	** 0.78798	** 0.94277	−0.15800	1	
Tension	0.06524	** 0.82219	0.14890	0.10185	** 0.78561	−0.01465	1

* $p < 0.00001$, ** $p < 0.00000$.

5.2.3. Qualitative Results

After the initial presentation, instructional videos, game session, and online survey, the authors conducted semi-structured interviews to gather qualitative feedback on the students' subjective opinions and concerns regarding the educational 3D maze game about climate heritage vulnerability. Four randomly selected students were interviewed for approximately two hours. The interviewees appeared to be predominantly passive game players who preferred popular single-player video games such as 2D platformers, puzzles, and role-playing games. While they greatly appreciated the game validation process, they shared concerns about the online survey finding it boring, containing too many questions per mini-game, and taking too long to complete.

Regarding the game itself, the students found the idea to be “very amazing and appealing” and highly appreciated the maze structure, game interface, and audio-visual effects. They liked the organization and presentation of the learning content but found learning boards with many consecutive slides practically unusable. The students enjoyed all the mini-games, including their mechanics, dynamics, audio-visual effects, and embedded educational content. They suggested a future inclusion of 3D models of cultural monuments and simulation of natural processes inside the maze, e.g., wind erosion, rising water levels in flooded maze halls, etc. As well, some of the interviewees recommended the inclusion of virtual players, i.e., non-player characters (NPCs), who should act as tutors [47], guiding

the player through the maze and providing valuable contextual hints while playing a mini-game [48].

6. Discussion

6.1. Answers to the Research Questions

The validation of the Vulnerability game provided insightful observations of its overall effectiveness and learnability. The higher values of Positive Affect, Immersion, Competence, and Flow, together with the lower values of Tension and Negative Affect, proved the game experience of the Vulnerability game to be better. Considering the attributes of learnability, the Vulnerability game outperforms the Resilience game (RQ1). The structured methodology and comprehensive survey design facilitated a robust analysis of the game's effectiveness in achieving educational outcomes. Thanks to the design methodologies applied to the construction of this game, the playing outcomes, plus some of the learnability parameters and the game experience factors, were proven to be significantly improved compared to the Resilience game (RQ2). The Vulnerability game session revealed significant engagement, with an average playing time of approximately 27 min, exceeding that of the Resilience game with circa 1/6. Although finding all hidden objects or playing all mini-games was not mandatory, players achieved higher mean scores at about 25%.

On the other hand, the mean number of hidden objects found exceeded those found for the Resilience game by 1/6, indicating the effectiveness of the game design focused on sustaining interest and enhancing learnability. Statistically significant correlations between playing time, game scores, and quiz performance indicate a cohesive learning experience. Additionally, improvements in Ease of Learning and Informative Feedback were noted, pointing to incremental enhancements in game design. Therefore, the Vulnerability game has achieved higher learning outcomes, game experience, and game learnability than the Resilience game. The mini-games within the Vulnerability maze received positive feedback, particularly regarding Positive Affect, Competence, Immersion, and Flow. Despite the overall favorable reception, aspects such as Tension and Negative Affect in certain mini-games, like "Rolling balls", highlighted areas for potential refinement. Comparative analysis of the Resilience game indicated improvements in Positive Affect and Flow, emphasizing the game's engaging nature. Since both games have similar educational content and the same level of playing difficulty, the enhanced design of the Vulnerability game is the only reason for the improved playing outcomes, learnability, and game experience (RQ2).

The authors found some medium correlations between the attributes of learnability—Predictability, Informative feedback, Ease of Learning, Familiarity, and Consistency—at $p < 0.5$, similar to those found in the evaluation of the "Let Us Save Venice" game (RQ3). The interrelations between game experience attributes appear much stronger and more significant than those found for the Resilience game [13]. Finally, it was found that age, gender, and amount of video game playing do not influence the learnability attributes but have a large effect size on some of the game experience components (RQ4).

The inductive reasoning method applied to the answers from the semi-structured interviews provided deeper insights into player perceptions. While the educational content and game mechanics were well-appreciated, suggestions for future improvements included 3D models of cultural monuments, simulations of natural processes, and NPCs to guide players. These recommendations suggest some directions for the enhancement of the game regarding educational impact and user engagement. They will be important for the future integration of educational games as a part of learning course curricula.

6.2. Limitations of the Study

The most significant limitation of the presented study is that the field trial and evaluation of the serious game were implemented only within the e-CREHA project during the intensive study program on “Climate impacts and heritage vulnerabilities” hosted by the University of Molise, Italy, in September 2022. The participants, aged between 18 and 31, included a mix of Bachelor, Master, and PhD students from various partner institutions. The majority had limited experience with video games, particularly educational ones, which reflects the game’s accessibility to non-gamers. The number of the sample—participating students was limited ($N = 22$). Hence, the study covers only the students involved in the project activities. Despite being of different nationalities, they may share some learning and cultural aptitudes concerning serious games. Further, the students are distributed unequally in terms of gender and university specialties, where female and civil engineering students prevail. The profile of survey participants is not balanced—the ratio of female to male students is 16 to 6, and most students do not have gaming experience.

The Vulnerability game was accessed as a preliminary version. The final version will address the critical students’ remarks and use the improved user interface of the new version of the APOGEE platform.

7. Conclusions

The article presents results from the validation of the video maze game about heritage vulnerability to extreme climate changes, with learning content and mini-games selected by applying the revised Bloom taxonomy. The findings prove its better effectiveness and learnability compared to another maze game dedicated to climate heritage resilience. Also, validating the Vulnerability game reveals statistically significant improvements in learnability and game experience compared to the Resilience game, thanks to applying the Bloom framework and the closer collaboration with domain specialists for creating the learning content. Therefore, these design approaches were proven to create a video game that is more suitable for raising awareness of the educational content integrated into the game. The students reported high engagement in the game playing; they achieved higher scores with more hidden objects found in longer average playing time. On the other hand, the interviewees suggested future improvements to the maze games, such as including 3D models and NPCs, to enhance educational impact and user engagement.

The present findings about the learnability and game experience of the Resilience and Vulnerability education maze games encourage educators at the University of Molise to apply them in the “Territorial project” and “Geomatics” classes of the Master’s degree in Civil Engineering. Such game-based learning will support the definition of project works scenarios of CRSSD of regional contexts, as well as in the class of “Territorial project of heritage” of the Master’s degree in Management of Tourism and Cultural Heritage, to integrate climate “resiliency vulnerability” issues in the proposals of tourism valorization of heritage. All classes use the contents created in the framework of the e-CREHA project, in particular, the e-learning media resources and the educational video maze game with integrated mini-games. Students show interest in these teaching instruments that effectively support the learning process.

The Vulnerability video game integrated into the activities provided by the e-CREHA project also serves to support students of the project partner universities in the process of constructing knowledge about the concept of vulnerability of built cultural heritage to the harmful effects of climate change, also with a focus on the specific vulnerabilities of the regional context such as landslides, floods, droughts, sea level rise. In this sense, it supported the drafting of the project scenarios related to four case study areas (see Section 4.3), representing a valuable tool to improve “traditional” teaching to foster the

raising of awareness, both in students and in professionals already working in heritage-related fields. Thus, the educational maze games for cultural heritage could be considered a relevant result in light of the general scarce integration of climate resilience action and (self) sustainable development practices, both in literature and case studies. This finding highlights the importance of designing integrated teaching tools capable of providing students and professionals with a diverse and innovative planning approach to tackle effectively the effects of climate change.

Future work will eliminate the limitations of the presented study by addressing a larger number of participants with various profiles to get a comprehensive grasp of how different cultural backgrounds and levels of gaming familiarity impact educational outcomes. Also, further research should eliminate the critical problems with the accessibility of learning content that have been recognized, e.g., cumbersome instructional boards with many slides. Revising the questionnaire will result in a more compact survey, improving the quality of the answers and the participants' overall experience.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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