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H5P-Based Matching Game for Training Graphs of Internal Forces in Structural Analysis

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Abstract: The teaching of structural analysis is essential in the training of undergraduate students who will be qualified in structural calculations. The use of games in learning can motivate students and improve their performances in evaluations. To this end, H5P-based matching games have been adopted in Moodle for a structural analysis course as an optional assignment to train graphs of internal forces (GIFs). Although the students knew that participating in the games would positively impact their grades, they were not informed of the exact number of extra points they would receive based on their performances. The engagement, motivation and performance of the students were analyzed using various statistics. Furthermore, the effectiveness of the game in facilitating knowledge acquisition was evaluated by comparing the students' performances in the games to their performances in the GIF exercises during face-to-face examinations. The study found that the students who participated in the games exhibited high levels of motivation and engagement. In addition, the results indicate that the participants had a moderately improved understanding of GIFs when taking the course examinations.

Keywords: blended learning; gamification; H5P; higher education; structural analysis

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1. Introduction

To ensure the effectiveness of the learning process, educators must consistently integrate innovative technologies and cultivate novel approaches to efficiently achieve predetermined educational objectives. At the same time, they should actively engage with communities of educational experts, fostering knowledge exchange through the exploration of pedagogical resources that facilitate an effective educational process. The utilization of novel technologies within platforms that facilitate the ongoing progression of an engaged learning procedure presents an interesting challenge for educators, as they must become proficient in employing the technology to enhance student learning.

Gamification in higher education involves the integration of gaming elements and design principles into the learning process to increase student engagement, motivation and overall learning outcomes. In this sense, assessments in the forms of quizzes, puzzles or scenario-based challenges with immediate feedback have been introduced in higher education in recent years, with point systems introduced to reward students for their achievements.

The teaching of structural analysis is fundamental to the training of undergraduate students who will be qualified in structural calculations. Architects in Spain are qualified in structural calculations, which allows them to dimension or check the structural elements in buildings.

The aim of developing gamification strategies in structural analysis education is to improve the understanding and learning of graphs of internal forces (GIFs). GIFs are representations of the bending, normal and tangential stresses experienced by points on the directrix of a structure. They are designed to focus on the properties that relate load schemes to shear forces and bending moments. By playing this game, students can more easily identify the typical shapes of GIFs associated with loading systems.

2. Background

2.1. Gamification in Higher Education

Gamification is a recent concept that adopts game elements in non-gaming contexts, such as education, to engage users and encourage them to adopt specific behaviors [1]. Games in learning can motivate students because they have an inherent ability to capture and hold their attention, making the learning process more enjoyable. Moreover, the competitive and rewarding nature of games can create a sense of achievement and motivate students to actively participate in the learning experience. Research studies highlight the importance of interactive and engaging learning methods [2].

The literature highlights the importance of interactive and engaging learning methods [3,4]. These methods not only make learning enjoyable but also promote active participation and improved retention and understanding while facilitating collaboration and peer interaction [5]. In this context, games encourage active student participation. Interactive learning methods require students to actively engage with the content, promoting a hands-on approach to learning [6]. Through games and interactive activities, students are more likely to participate willingly, leading to the better retention and understanding of the material [7–9]. Interactive methods often involve repetition in a more enjoyable form, reinforcing key concepts through practice [10].

Customization in educational games can provide different levels of difficulty, allowing students to progress at their own paces and providing challenges that match their skill levels [11]. Today's students are increasingly distracted, and it is harder to keep them motivated with conventional learning methods. Particularly, structural analysis learning requires careful study to understand and assimilate the applied mechanics concepts. Hence, there is a need for innovative and effective learning tools in these types of courses. In this context, gamification strategies help instructors to keep students focused and motivated. In addition, a fundamental advantage of educational games is that they can provide immediate feedback to students, allowing them to understand their mistakes and learn from them immediately. In fact, rapid feedback is essential for effective learning, as it helps students identify areas for improvement and reinforces correct understanding [12].

While gamification has gained attention in various fields, including general education and business, its application and effectiveness within specific disciplines, such as applied sciences, have been relatively understudied [13].

2.2. Blended Learning

Blended learning refers to an educational approach that combines traditional face-to-face instruction with online learning activities. This hybrid model integrates the strengths of both face-to-face and online learning, creating a more flexible and personalized educational experience [14]. In this sense, online platforms can provide a wealth of educational resources, including games, which can supplement traditional classroom materials. Students can access these resources anytime and anywhere, promoting continuous learning beyond the confines of the physical classroom. In addition, blended learning allows for a variety of assessment methods, including both traditional face-to-face and online assessments. This variety can help educators measure student understanding in a variety formats. The digital environment, combined with other activities, can address all the skills and competencies to be achieved [15]. Ortiz et al. [16] reported successful results in blended-learning activities, highlighting the effectiveness of a blended evaluation that includes continuous online assessment and one or more face-to-face exams.

Online education delivery technologies can be categorized into two main groups: asynchronous and synchronous. Asynchronous learning systems are based on communication platforms that do not require timely engagement among the individuals involved in the educational process [17]. Based on students' evaluation results, previous studies have suggested that asynchronous assignments in blended learning can help to maintain the level of learning and consolidate knowledge, even in adverse conditions and under severe constraints [18–22]. Learning management platforms for distance learning facilitate interactions between participants using a framework known as 'request–response'. These interactions are not limited by time constraints. One widely used online learning management platform is the Modular Object-Oriented Dynamic Learning Environment (Moodle), which stands out for its high interoperability, extensive toolset and advanced features. These features can benefit instructors by promoting student engagement and improving learning outcomes. Research has shown that Moodle is an effective tool for measuring student learning performances in relation to their final evaluations [23].

The tools developed to support blended learning also have some weaknesses. Educational applications may lose their effectiveness over time, so continuous improvement is necessary. In previous developments of structural analysis courses, and particularly concerning GIFs, automatic self-correction systems have been deployed in Moodle for undergraduate students [24]. Further, drag-and-drop questions have also been implemented in Moodle, which can be seen as a precursor to the development presented in this paper [25].

2.3. H5P in Education

H5P is a free and open-source content collaboration framework based on JavaScript. H5P, which stands for the HTML5 Package, strives to facilitate the creation, distribution and utilization of interactive HTML5 content, with the intention of making it accessible to all individuals [26]. Moodle supports the integration of H5P content for improving the interactivity of and engagement with online courses [27]. H5P activities can be integrated into the Moodle gradebook.

H5P-based interactive activities have been incorporated in recent years. Studies have shown that they can enhance several of the advantages found in other blended-learning activities, such as positive impacts on student assessment results, increased learner satisfaction, higher motivation and improved student information retention [27–29]. According to recent research, students who participated in interactive H5P activities achieved higher scores than those who participated in traditional online activities [15].

The successful alignment of interactive H5P activities with learning outcomes allows self-paced and self-directed learning, inducing higher student engagement in self-directed study [30]. Moreover, participants find interactive H5P activities easier, and they increase their motivation [15].

3. Materials and Methods

The research subject was an H5P-based matching game designed for undergraduate architecture students enrolled in the structural analysis course. The analyzed sample consisted of 55 students who took the exam in one of the groups to which the subject of structural analysis was taught during the autumn semester of the 2023–2024 academic year. The exam is a face-to-face written test with blind correction. This helped to reduce bias in the data collection and analysis. The exam includes a specific question that requires determining the GIFs of a structure with a loading system, among others. The experiment complied with ethical guidelines for research involving human participants, as the participants' privacy and confidentiality were fully protected.

This course follows a blended-learning scheme with weekly assignments, both synchronous and asynchronous [18]. The final grade in the course consists of three grades. Two of them correspond to the face-to-face exams, with a weight of 35% each, and the remaining 30% is obtained with the completion of the continuous-evaluation weekly assignments. In addition to the required weekly assignments, students were given the option to complete two H5P-based activities per week for asynchronous learning in six of the course weeks, resulting in a total of 12 assignments. Each activity can add up to one extra point to the student's weekly score, allowing students to increase their weekly scores by up to two points out of ten. This means that students can obtain additional points to compensate for the scores not obtained in the other course evaluations. Without considering the orientation of the game towards the preparation of face-to-face exams, H5P games account for 2.4% of the total course grade. Although students knew that participating in the games would positively impact their grades, they were not informed of the exact number of extra points (out of a maximum of one per game) they would receive based on their performances in the game. It was therefore expected that the students would attempt to complete as many levels of the game as possible instead of conforming.

The selected game type was image pairing without retry [31]. Because the drawing of GIFs is fundamental to building structure analysis, this game can be considered an effective method and graphic component to include in architecture studies. Each assignment consists of matching games that increase in difficulty from levels 1 to 10. A sufficient number of game levels of appropriate difficulty are arranged to observe various patterns in the students' skills, motivations and learning abilities. Each game, including all its levels, corresponds to several variations (for example, symmetric) of a unique structure with different load schemes. Numerical calculations are not necessary to match the images; it is enough to identify the structure geometry, the load system and the GIF layout. Participants can check the correct answers after submitting their answers. However, each time a game level is replayed, a new quiz is randomly generated.

The games propose two-dimensional planar structures, namely, beams and frames. During the first two weeks, isostatic structures were proposed. For the remainder of the course, hyperstatic structures with increasingly complex topologies were introduced, which likely increased the difficulty as the course progressed. The load systems of the building structures combine point loads, moments (torque) and uniform loads along varying stretches, which are the most common load typologies. It is important for students to identify and associate the load patterns and GIF patterns (Table 1), as well as the contour conditions. Mathematical relationships between the loads, shear forces and bending moments can be derived from the equilibrium equations in two dimensions of a slice, as follows [32]:

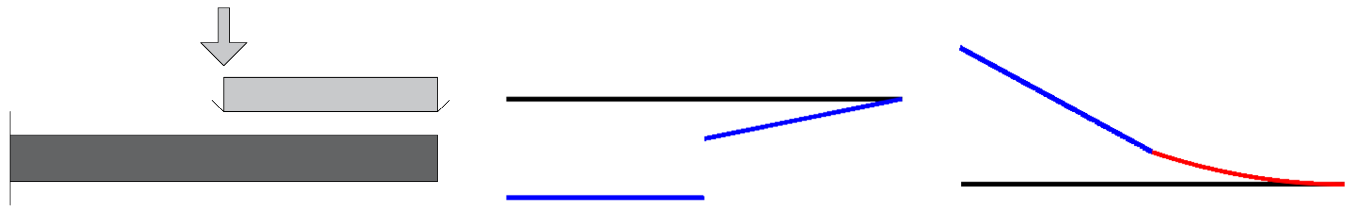
$$M = \frac{dV}{ds} = -\frac{d^2q}{ds^2} \tag{1}$$

where q is the load, V is the shear force, M is the bending moment and s is the curvilinear coordinate along the directrix of the structural member.

Table 1. Relationships between load patterns and graphs of internal forces.

Load System	Shear Force	Bending Moment
Point load	Jump	Angular point
Uniform load	Linear variation	Square variation
No load	Constant	Linear variation

Figure 1a illustrates a cantilever beam structure with a uniform load on the right half of its length and a point load at the center used in one of the H5P games. Figure 1b shows the corresponding graph of shear forces. It displays a constant value on the right half of its length due to the absence of loads, a jump at the point where the point load is located and a uniform variation that ends in zero on the right half due to the uniform load. Figure 1c shows the counterpart graph of bending moments. It displays a uniform variation on the left half due to the absence of loads on this stretch and the subsequent constant value of the shear forces. An angular point is formed at the midpoint of the graph of bending moments due to the point load and the subsequent jump in the shear forces. The bending moment is given by a parabolic curve on the right-half stretch of the beam that ends in zero due to the uniform load and the subsequent linear variation of the shear forces. To ensure the correct identification of the line shapes on the graphs, straight lines are plotted in blue and parabolic curves are plotted in red.



(**a**) (**b**) (**c**)

Figure 1. (**a**) Cantilever beam with load system; (**b**) graph of shear forces; (**c**) graph of bending moments. Straight lines are plotted in blue and parabolic curves are plotted in red.

Figure 2a shows an example of the initial setting of the image-pairing game. The figures are separated into two areas, each containing mixed images of the loaded structure, graphs of bending moments and graphs of shear forces. It can also be seen that the color code mentioned above is used to distinguish between the rectilinear and parabolic stretches of the graphs, which is necessary for matching the images. In any case, the proposed pair relationships are unambiguous. Students are required to drag images from the left area and drop them onto the corresponding image, one by one. If necessary, the answers can be rectified and dropped back to the left area. After submitting their answers by clicking on the check button, students can view their raw scores at each level of the game (Figure 2b). Although students were informed of their weekly scores, they were not provided with information on how the total game scores were calculated and added to the weekly scores. The score for each level increases with its difficulty, as shown in Table 2. Nevertheless, all the game scores are normalized so that the student with the highest score receives one point and the other students receive a fraction of a point proportional to their scores, according to the following equation:

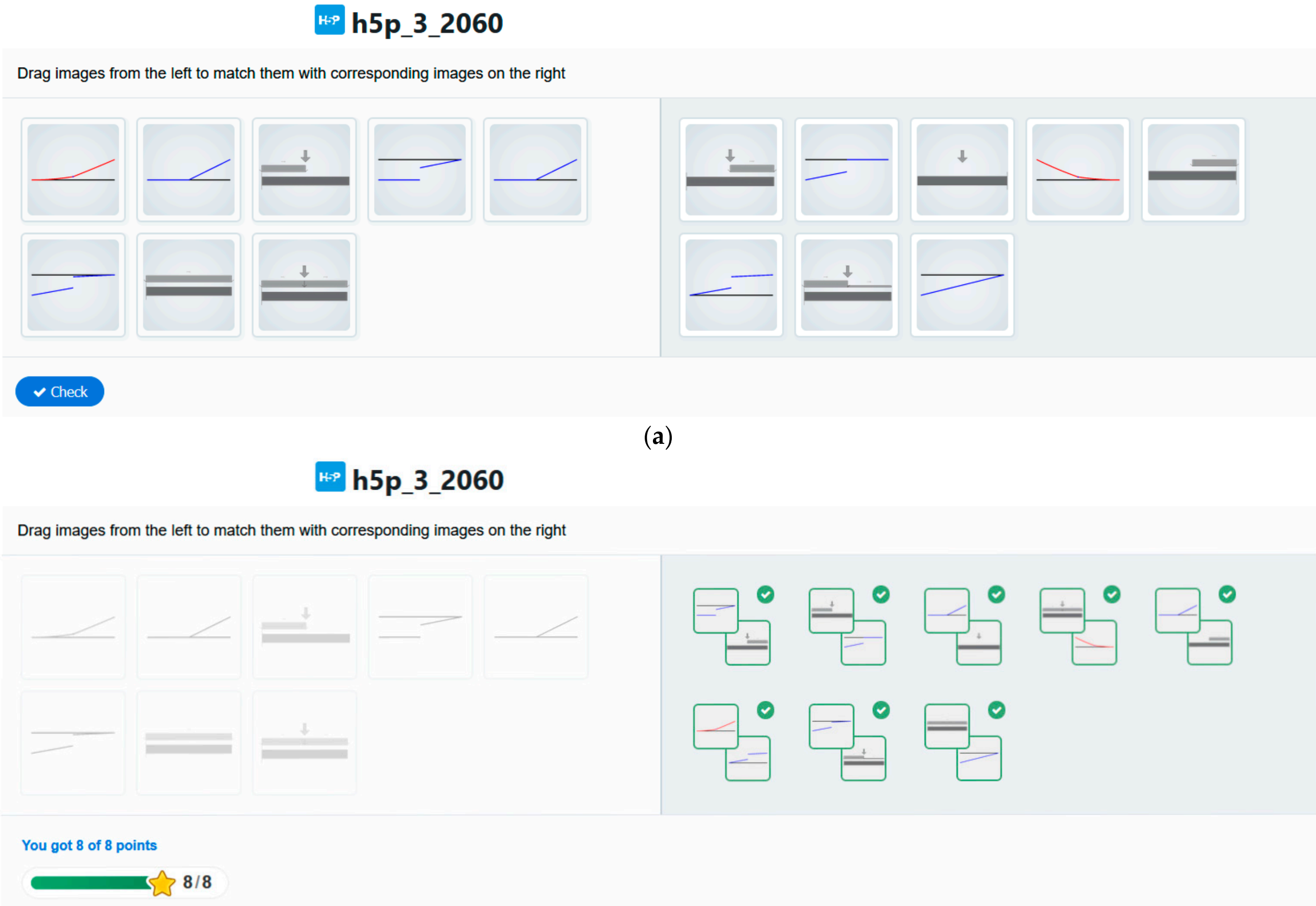
$$s_{t,j} = \frac{\sum_{i=1}^{n} w_i \cdot s_{i,j}}{s_{t,max} \cdot \sum_{i=1}^{n} w_i \cdot s_{i,max}} \quad (2)$$

where $s_{t,j}$ is the score received by student j in a game; w_i is the relative weight of the score level according to Table 2; $s_{i,j}$ is the score awarded at the *i*-th level to student *j*; $s_{t,max}$ is the highest score obtained by the students in the game; $s_{i,max}$ is the maximum possible score at the *i*-th level; and n is the number of levels in the game.

It is assumed that this measure motivates students to achieve as many levels as possible. To progress to the next level of the game, participants must attain 100% of the level score in the first level and 50% of the level score in the subsequent levels. An unlimited number of attempts is allowed for each level, including improvement in the level score, even if the participant has already progressed to the next level.

Table 2. Game levels, numbers of image pairs and weighted scores.

Level	Number of Pairs	Maximum Relative Score
1	2	1
2	4	1.25
3	8	1.5
4	14	1.75
5	23	2
6	34	2.25
7	47	2.5
8	62	2.75
9	80	3
10	100	3.25



(a)

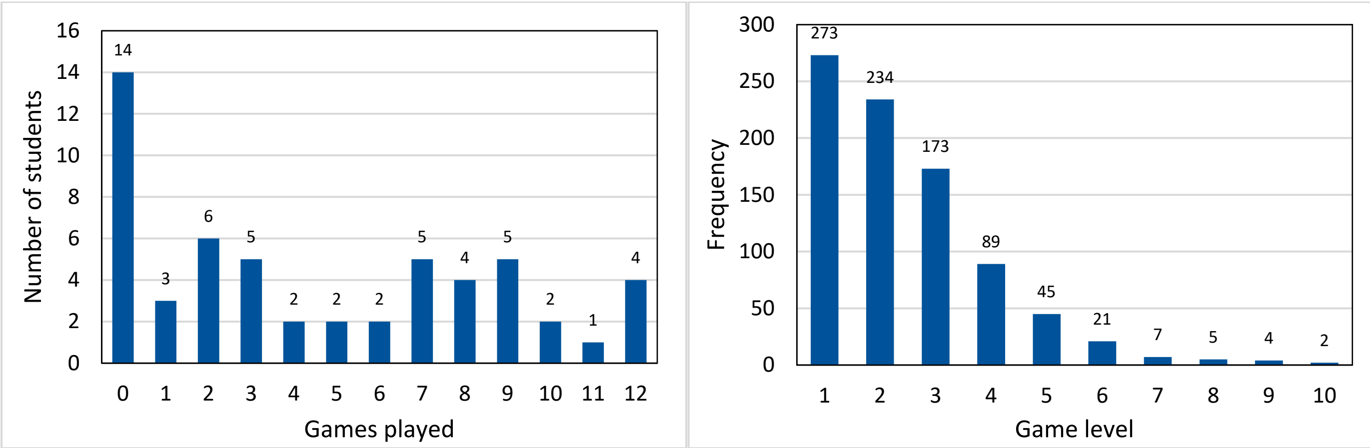
(b)

Figure 2. Interface of H5P image-pairing game at level 3: (**a**) initial view; (**b**) view after checking the answers.

4. Results and Discussion

In this section, the outcomes of the analysis of the students' performance data and findings are presented, interpreted and discussed. Through an exploration of the empirical data and statistical analyses, this section aims to provide insights into the engagement, motivation, effectiveness, impact and observed patterns in the course due to the implementation of the H5P games. The ensuing discussion delves into the implications of the results, their alignment with the existing literature and potential avenues for further research.

The level of student engagement with the H5P games can be estimated by analyzing the number of games played and the corresponding levels achieved. Figure 3a illustrates the numbers of students who played a certain number of games, ranging from not playing at all (0 games) to playing all 12 games available. Out of the total number of students, 41 students played at least one game, while only 4 played all the games. The distribution of the numbers of games played appears to be quite disperse. This suggests a diverse range of student engagement levels: while some attempted only a few games, some found the games moderately appealing, and others demonstrated high involvement. Figure 3b displays a histogram of the game levels played by the students, regardless of the number of times they were played. While a relatively high number of students played the three lowest levels of the H5P games, there was a noticeable decline from levels 4 to 6. In addition, the students barely played level 7 and above. These results suggest that the difficulty of the last few levels might have discouraged the students.



(**a**) (**b**)

Figure 3. (**a**) Histogram of numbers of games played by the students, showing that the students' engagement varied, with some trying a few games, others finding them somewhat appealing and some highly involved; (**b**) histogram of levels played by the students with a decline in the higher levels, indicating possible discouragement due to difficulty.

The performances of the participants in the GIF H5P games are illustrated by the scores obtained throughout the game levels. Figure 4 displays the graph of the average level scores, with the x-axis representing the game levels, and the y-axis representing the average scores. It can be noted that the participants achieved very high scores in the game levels played, except for level 9. Therefore, the participants not only aimed to move to the next level but also to obtain the highest possible score. It is important to note that the participants achieved the maximum scores in all cases in which they reached the last level of the game, despite its infrequent occurrence.

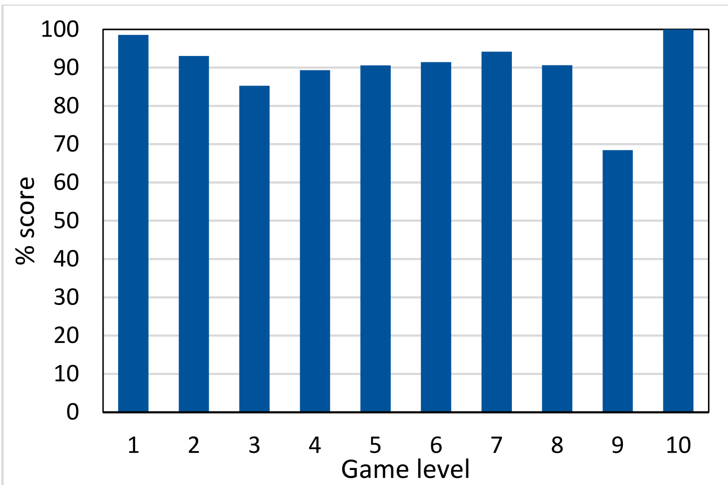


Figure 4. Average scores obtained in H5P game levels, showing that participants generally scored highly in game levels, except level 9. They aimed to progress and maximize their scores, often achieving the maximum scores.

Figure 5 displays the average number of attempts per level across all the games. The upward trend in the average number of attempts is likely due to the increasing difficulty as the participants progressed through the levels. Table 2 illustrates the evolution of the number of pairs in the game, indicating a significant increase in difficulty with each level. However, it could also be interpreted that the most skilled students, who required the fewest attempts to complete a level of the game, were the ones who completed the most levels. Conversely the least skilled students dropped out of the game at low levels. This could contribute to smoothing the trend of increasing attempts in successive levels. The graph also shows the average number of attempts required to reach the minimum score that allows access to a higher level of the game in light blue. At levels 2–8, few participants attempted to improve their scores beyond the minimum threshold required to move to the next level. The feedback provided at the end of each level may have encouraged additional attempts. This suggests that some students were highly motivated to improve. At the highest levels, no additional attempts to improve the scores were registered due to the increased difficulty and low number of participants who reached these levels.

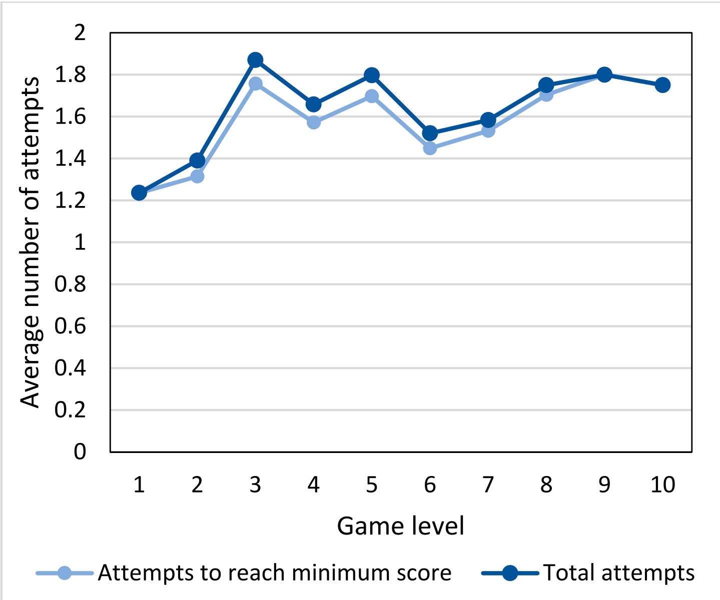


Figure 5. Average numbers of attempts at H5P game levels. The average numbers of attempts increase slightly as higher levels are reached, although only the most motivated or skilled students gained access to the higher levels.

After analyzing the evolution of the attempts in the 12 games arranged for the course, the evolution of the participants' learning was studied. For this purpose, the attempts in the first three levels of each game were considered, dividing the sample between games 1–3 and games 4–12. The purpose of this analysis was to determine whether the students required fewer attempts to reach the minimum score in games 4–12 compared to games 1–3. To analyze the data, RStudio 1.3.959 software was used. A one-tailed Mann–Whitney U test was performed due to the independent nature of the two samples and the non-normality of the sample distributions, as the number of attempts is a discrete quantitative variable. Table 3 presents the main statistics of the test. The null hypothesis that the samples come from the same distribution can be rejected based on the p-value of 0.002. This suggests that the participants required fewer attempts to progress to the next level of the game due to their increased knowledge of the load systems of structures and GIFs, despite the progressive increase in the game difficulty throughout the course.

Table 3. Summary of Mann–Whitney U test parameters.

Variable	Games 1–3	Games 4–12
Mean	1.535	1.426
Variance	0.875	0.646
Number of observations	241	599
Degrees of freedom	240	598

The analysis of the effectiveness of the devised games involves a comparison of the student performances in the H5P games and in the GIF question on the face-to-face exam. For this purpose, the average score in the H5P games for each student, with possible values between 0 and 1, and the total score in the GIF question on the exam, with a maximum score of four points, were considered. First, the Pearson correlation coefficient was calculated to determine the strength and direction of the linear relationship between the two data series. The coefficient value obtained was 0.2, indicating a weak positive correlation between the variables due to its proximity to zero. Secondly, because the score in the GIF question of the exam is dependent on training GIFs with H5P games, a linear regression was fitted between the two series. The estimates obtained are presented in Table 4. The intercept is significantly greater than zero with a high confidence level. The H5P average score had a positive effect on the exam score, which was significant at an 85% confidence level. These results suggest that some participants found the game's representation of GIFs associated with a system of loads in a structure more addictive than useful. Figure 6 illustrates the scatterplot of the average scores in the H5P games, the scores for the GIFs on the exam and the regression line.

Table 4. Summary of linear regression output.

Variable	Estimate	Standard Error	*p* Value
Intercept	2.463	0.232	0
H5P average score	1.005	0.631	0.15

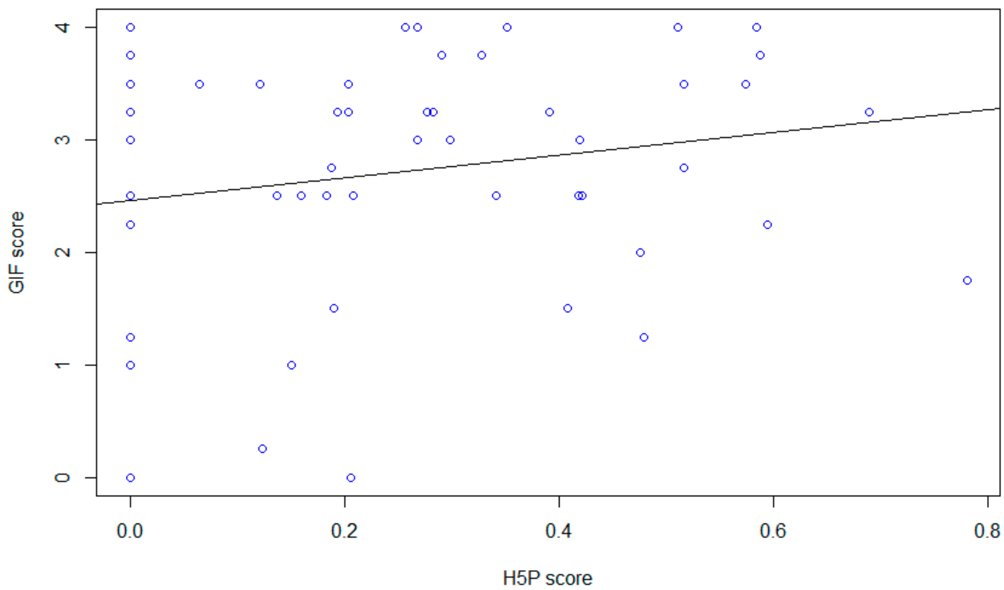


Figure 6. Scatterplot of average scores in H5P games, scores for GIFs on the exam and regression line.

5. Conclusions

Incorporating interactive and engaging learning methods into the curriculum, such as educational games, is intended to enhance students' motivation towards, participation in and understanding of the material, leading to more effective and enjoyable learning experiences. This study included a sufficient number of game levels, with appropriate levels of difficulty, to observe different patterns in the students' skills, motivations and learning abilities. The game was designed to help students practice working with a wide variety of diagrams, allowing them to internalize the properties of load systems in building structures, as well as their corresponding GIFs.

The study presented in this document tested the suitability of H5P games to support and reinforce the teaching of GIFs. The results showed that the students who participated in the games had varying levels of motivation and engagement. Motivation was higher in the game levels with lower difficulties and decreased as the difficulty increased. Bearing in mind that the matching games were arranged according to increasing levels of difficulty from 1 to 10, it can be concluded that intermediate levels 5 or 6 are enough for practicing the representation of GIFs. Thanks to the feedback provided by the analysis of the results for the H5P games, it can be concluded that some students were highly motivated and made additional attempts to improve their scores, even after successfully completing certain game levels. This helped them intensify their acquisition of knowledge and skills. In addition, the results suggest that the participants in the H5P games improved their knowledge of GIFs as the course progressed, particularly when faced with the face-to-face examinations. While there is a positive correlation between the engagement with the H5P games and the performance on the GIF-related questions on the exams, the correlation is relatively weak, indicating that other factors may also affect the exam performance. However, it is worth highlighting the success of the gamification strategy for its low relative weight within the final grade of the course.

Finally, this study emphasizes the importance of carefully designing game-based teaching strategies to promote continuous learning, ensure sufficient student motivation, improve knowledge acquisition and guarantee adequate skill development.

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Institutional Review Board Statement: Approval Waived. There are several factors that may contribute to the determination that formal approval from an ethics committee or IRB is not required: No Risk for Participants: The research involves routine educational practices such as grading, assessment, or evaluation of students' academic performance. The data collected are completely anonymized and not sensitive. In such a case, the potential harm to participants is null. Standard Educational Practices: The research is conducted as part of standard educational practices, and the data collected are used for administrative or pedagogical purposes within the university, it may not be viewed as research that requires external ethical oversight. Internal university policies and procedures may be sufficient to ensure the ethical treatment of participants. No Experimental Interventions: The study involves only the collection and analysis of existing data (scores and exam grades) without any experimental interventions or manipulations, it may be considered exempt from formal ethical review. The focus is on observing and analyzing pre-existing data rather than introducing changes that could impact participants. Maintaining Anonymity and Confidentiality: The researchers ensure that the data are collected and reported maintaining the anonymity and confidentiality of the students, the risks associated with potential harm or privacy breaches are negligible. This determines that formal ethical review is not necessary. Compliance with Institutional Policies: The study aligns with the ethical guidelines and policies of the university and the current legal framework of the E.U. The researchers adhere to established ethical standards within the academic environment. It is therefore unnecessary to seek additional external approval.

Informed Consent Statement: Patient consent was waived due to data anonymization during collection and analysis.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions regarding the participating university departments.

Conflicts of Interest: The authors declare no conflicts of interest.

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