Mastering the Game: How Level Structure and Game Elements Shape Competency Acquisition

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Abstract: Understanding the dynamics of level structure and game elements in digital educational games is paramount to fostering competency acquisition. How levels are organized within a game, along with the use of various game elements, has a significant impact on the learning outcomes and skill development of individuals. Through the strategic design and implementation of these components, educational games can effectively engage learners and facilitate the acquisition of competencies in multiple domains. In addition to structure, the integration of gamification elements can have a profound impact on learner engagement and sustainable skill acquisition. Therefore, a key element for the success of a serious game is to create appropriate personalization and a balanced relationship between learning and gaming experience. As a result, a mini-game called "Basketball Physics Challenge" has been designed to be integrated into an intelligent, adaptive physical learning game centered around force and motion as part of an ongoing research project. By playing the game "Basketball Physics Challenge", players will apply their understanding of basic physics principles in a realistic, interactive, and virtual setting. An experimental design was used to test the mini-game, in which a gamified and a non-gamified version were used and compared. 20 participants completed the experiment, and their learning progress was meticulously tracked. Using competency-based knowledge space theory, the mini-game facilitated in-game competency assessment, enabled monitoring of learning progress, tailored learning experiences, and provided individualized formative feedback. The pilot was used to develop and implement a competency model that will be the subject of future in-depth studies. The results indicated that the gamified version of the game led to slightly higher engagement and performance levels compared to the non-gamified version, although the difference in learning outcomes between the two versions was not statistically significant. The analysis also showed that an optimal number of levels and a balanced integration of game elements are crucial for maintaining engagement without causing cognitive overload. Furthermore, the order in which the game versions were presented affected player performance, with initial exposure to gamification leading to better outcomes. These findings provide valuable information for the design of educational games and their effectiveness in skill acquisition. This research supports the development of powerful educational technologies that enhance learning through a coherent level structure and meaningful use of game elements that effectively promote learner engagement.

Keywords: Serious Games, Level Structure, Game Elements, Competency-based Knowledge Space Theory, Physics

1. Theoretical Background

1.1 Introduction to Serious Games and Gamification.

Serious games, also known as game-based learning, have gained significant attention in various fields such as education, healthcare, and behavioral change interventions. They are designed to provide specific learning content and assess the learning progress of players. Above all, the aim of serious games is to maintain and promote the motivation and engagement of players in the learning process (Haruna et al., 2023). Spieler and Slany (2018) divide the game design elements into three main categories: (1) game world, (2) game structure, and (3) gameplay. These game elements represent the core aspects of a serious game. They must be present in order to enable interactive and entertaining learning. Gamification, on the other hand, uses game mechanics or elements in non-game contexts to improve teaching and learning (Deterding et al., 2011). In contrast to serious games, gamification is not a stand-alone product, but builds on existing learning objects or tools. Game mechanics such as points, badges, leaderboards, and levels are crucial aspects in developing gamification for education to make learning interactive and fun.

1.2 Effect of Serious Games

Serious games have been shown to be effective in improving learning outcomes and learner motivation. Incorporating game elements into educational environments tends to increase students' enjoyment of learning, which often goes hand in hand with intrinsic motivation, as serious games inherently provide stimulating elements such as interest and fun (Wouters et al., 2013). Because of the intrinsic motivation factor, games, with their informal, free-choice functions, provide an ideal platform for children to explore and learn about the properties of materials and objects in the learning environment on their own (Boyle, Connolly & Hainey, 2012).

In addition to intrinsic motivational factors, serious games also include extrinsic motivational factors by incorporating external rewards such as points or ratings (Brown, 2007; Gray et al., 2019; Zhang & Yu, 2022). Self-determination theory (SDT) plays an important role in understanding intrinsic and extrinsic motivation in serious games. SDT emphasizes the importance of autonomy, competence, and relatedness for intrinsic motivation, which is consistent with the idea that serious games provide an ideal platform for independent exploration and learning (DeSmet et al., 2014). Serious games not only leverage intrinsic motivation, but also incorporate extrinsic motivational factors such as rewards to further enhance engagement and retention of learning content (Roozeboom et al., 2015). In addition, serious games have been found to promote attitude change (Chow et al., 2020), further emphasizing the impact of these games on learner engagement and outcomes (Zairi et al., 2022). In summary, serious games and gamification strategies can effectively increase learner motivation and promote higher levels of learning by aligning with frameworks such as self-determination theory. By incorporating elements that address intrinsic and extrinsic motivations, serious games provide a dynamic and engaging learning environment that supports modern approaches to education.

2. Present Study

2.1 A Basketball Challenge

The primary goal of the Basketball Physics Challenge project was to improve players' understanding of basic physics concepts through an interactive educational game. The project aimed to go beyond traditional teaching methods and deliver physics education in an engaging and contextualized way. Given the increasing importance of digital educational technologies in the learning environment of modern classrooms, the game provided an innovative platform to explore theoretical concepts such as initial velocity, motion and trajectory, throwing angle, gravity, friction and air resistance in a realistic simulation. In addition to the main goal of improving physics understanding, another important concern of the project was to investigate the impact of gamification elements on the learning process. Gamification, or the integration of game elements into non-game contexts, has been shown to be an effective means of increasing learner motivation and engagement (Looyestyn et al., 2017; Sailer et al., 2020). The hypotheses (H1 to H5) outlined in the study are directly derived from these project goals.

For instance, H1 focuses on assessing whether participants using the gamified version of the "Basketball Physics Challenge" exhibit higher engagement levels and motivation compared to those using the non-gamified version, aligning with the project's aim to enhance learner engagement. H2 examines whether the gamified version leads to greater improvement in learning outcomes related to force and motion, which is essential for achieving the project's goal of enhancing physics understanding. H3 investigates the optimal number of game levels that maximizes the acquisition of competencies in force and motion without causing disengagement or cognitive overload, contributing to the project's objective of promoting effective learning experiences. Furthermore, H4 and H5 explore the differential impact of specific game elements and their sequencing on learning outcomes and engagement, directly addressing the project's interest in understanding the effectiveness of gamification elements in the learning process.

In the implementation phase, the hypotheses will serve as a guide to refine the Basketball Physics Challenge mini-game. This ensures the incorporation of various levels and gamification elements to effectively achieve the project's objectives. Through a pilot study and subsequent main study, the hypotheses will be empirically tested to provide valuable insights into the effectiveness of gamification in achieving the project's overarching goals of enhancing physics education through interactive and engaging learning experiences.

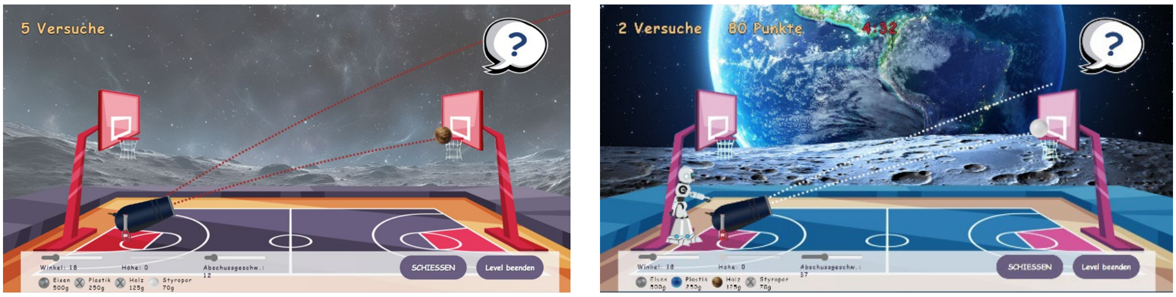
3. Methods

3.1 Participants

The participants of the study were 20 students recruited from a secondary school in Liechtenstein. The students attended an optional 10th grade, an additional year of education after completing the standard curriculum. The age range was 15-18 years *(M = 16.25, SD = .76)*, 10 students were female, 10 male, 65% of students had German as their mother tongue. Overall, the physics grades in the sample were at the lower end; The students were randomly divided into two groups.

3.2 Study Design

The project study used a crossover design to investigate the effects of gamification on performance and skill acquisition in an educational game. The goal was to compare the effectiveness of two versions of the game: a version with gamification elements and a version without gamification elements. Participants were randomly divided into two groups. One group started with one version and then switched to the other. This method made it possible to consider the individual differences of the participants as a control variable and at the same time reduce the total number of participants required.



Winkel: 18
Höhe: 0
Abschussgeschw.: 12

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Figure 1: Screenshots of the "Basketball Physics Challenge". The left picture shows the "Non-Gamification" version; the right picture shows the "Gamification" version).

The gamification version (version A) of the game included game elements such as scoring systems, time limits and competitions to increase motivation and engagement. The non-gamification version (version B) focused solely on the educational content without any additional game elements. The challenges and physical concepts were identical to those of the gamification version, but without the game incentives and competitive elements. The game behavior was recorded to capture data such as the changes in game mechanic settings, as well as temporal progression, scoring, and attempts, which were necessary for further analyses of skill acquisition.

3.3 Learning Task: Content of the Learning Task

The central learning task of the game was to enable players to understand and apply basic physics concepts in a simulated interactive environment. Players were encouraged not only to learn principles such as initial velocity, motion, and trajectory, throwing angle, gravity, friction, and air resistance, but also to actively apply them in the game environment. This took the form of a basketball game in which players had to throw the ball into a basket with a cannon by adjusting these variables. This encouraged experimental learning by allowing players to test hypotheses about physical effects and learn through direct feedback in the game.

3.4 Level Structure

To comprehensively cover the above educational objectives, a level system was developed that offers increasingly complex physical challenges. The structure of the game levels is designed to provide increasing complexity and challenge in terms of physical concepts. For this structuring, a competency model was developed based on international curricula with a focus on Switzerland (e.g. https://www.lehrplan21.ch). The first levels focused on simple concepts such as initial velocity and throwing angle to teach players basic handling and understanding of trajectory. As the game progressed, the tasks became more complex, and players had to consider advanced principles such as gravitational effects on different planets and the influence of environmental factors such as wind or vacuum. Each level aimed to illustrate a specific physics concept and deepen understanding through practical application. The gradual increase in difficulty served to continuously challenge the players without overwhelming them, thus promoting effective and sustainable knowledge acquisition.

3.5 Learning Outcome Measures: Performance Measures

Various performance measures were used to quantify learning progress. These included scores based on the accuracy of throws, success rates representing the ratio between successful throws and the total number of throws, and the number of throws required to complete a level. These metrics provided an objective assessment of players' skill and understanding of the physical concepts.

4. Results

Conducting data cleaning and preprocessing for the Basketball Physics Challenge provided important insights into player engagement and learning effects. First, a sample was removed due to incomplete data and atypical game behavior - a player who did not attempt a shot. Analysis of the data distribution using histograms and the Shapiro-Wilk test for normal distribution revealed a significantly asymmetric distribution of scores for both versions (A and B), indicating non-normally distributed data, with highly significant p-values below 0.001. The data also showed multimodal peaks and a wide spread in the histograms, suggesting that there are different types of players or that certain levels are differently difficult. This could also mean that some players have not fully understood the game mechanics, or that they regularly fail at certain points in the game. To enable a more detailed analysis and to further optimize the game, it was decided not to use data transformation for normalization and instead to use non-parametric methods for further analysis. This decision allows a more detailed investigation of the actual game interactions and learning progress, unaffected by the assumptions of normal distribution.

4.1 Scoring Progression, Insights Into Player Skill Development, and Effectiveness of Game Structure

This study aimed to analyze the score progression of the two different game versions and to identify possible differences in game performance between the different levels, as well as to obtain indications for a suitable level structure in the game. In both game versions, the average scores show a general increase from the beginning to the end of the level, with version A increasing from 139 points in level 1 to 2358 points in level 9, and version B increasing from 170 to 2293 points in level 8, only to decrease slightly to 2271 points in level 9 (Figure 2). This trend indicates an improvement in player skill. However, the drop at level 9 in version B could indicate decreasing motivation or increased difficulty, which may require an adjustment to the game design.

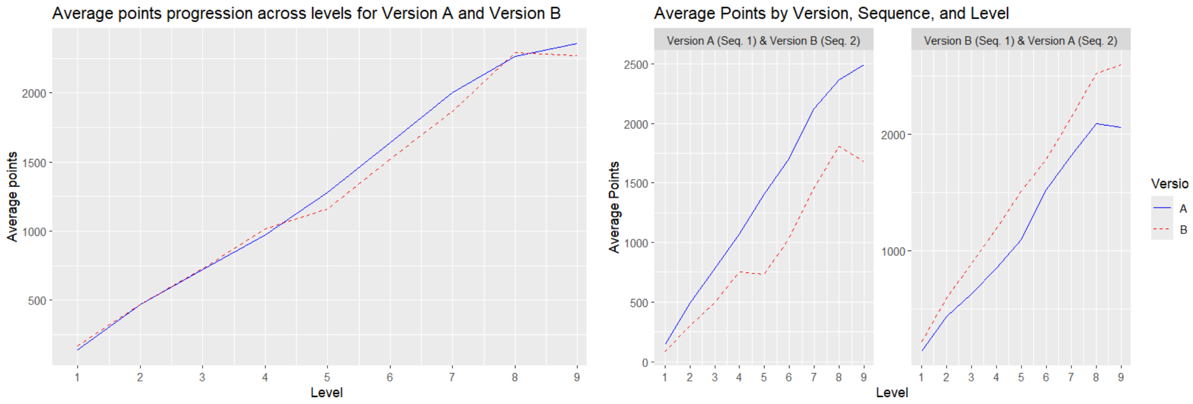

Figure 2 The average points progression by Version A and B across levels and the average points progression by Version A and B, sequence (1 = first game, 2 = second game), and level.

The Mann-Whitney U-test shows *(U = 796541, p = 0.64)* that there is no statistically significant difference between the scores of versions A (gamification) and B (non-gamification). This means that regardless of the gamification elements, both versions produce similar performance data from the participants. However, it was found that the mean score in version A *(M = 1275.22; SD = 850.60)* is slightly higher than in version B *(M = 1256.57; SD = 832.60)*, which could indicate that players generally perform better in version A or that the gamification elements have a positive effect on players' performance.

4.2 Sequence Influence

Examining the game versions in different sequences provides deeper insights into the differences in performance between versions A (gamification) and B (non-gamification) and their effects on the game outcome depending on the order in which the game versions are presented. Sequence 1 shows that both gamification (A) *(M = 1389.95; SD = 857.57)* and non-gamification (B) *(M = 1491.38; SD = 845.30)* reach high mean scores, with non-gamification reaching slightly higher scores. Sequence 2 shows a clear decrease in mean scores for both versions *(version A: M = 1098.33; SD = 809.24)*, especially for the non-gamification version *(M = 883.40; SD = 658.37)*. In the second sequence, the results are more consistent, possibly due to familiarity with the game. The

Kruskal-Wallis test for the combined variable (version & sequence) shows a highly significant difference between the different combinations of version and sequence *(Chi-square(3) = 182.68, p = . 2.2e-16)*. This result indicates that not only the sequence alone, but also the specific combination of gamification and non-gamification elements in different sequences has a significant influence on the game results. The Kruskal-Wallis post-hoc analysis using Dunn's method with Bonferroni correction confirms that both the specific game version (gamification vs. non-gamification) and the order of its presentation have a significant influence on the scores. The effect size between version A.1 (gamification played first) and version B.2 (non-gamification played in the second game run) *(r = 0.64)* shows that the probability that a randomly selected player from group A.1 achieves a higher score than a randomly selected player from group B.2. This effect is classified as “large”, which indicates that gamification presented first tends to lead to better results. The effect size *(r = -0.47)* between version B.1 (non-gamification played first) and version A.2 (gamification played in the second game run) shows that the probability of a higher score in group A.2 is about *37%* compared to group B.1. This indicates a small effect, with player performance being significantly worse when gamification is presented after non-gamification. According to Cohen (1988), r ≥ 0.1 describes a small effect, r ≥ 0.3 a medium effect and r ≥ 0.5 a large effect. These findings are critical for planning and designing future games or learning tools, especially in terms of how to present different content and methods to maximize engagement and performance.

4.3 Success Rate, how Effectively Players Overcome Certain Challenges

Success rate is a measure of how successful a particular event or action is, measured by the number of successful outcomes relative to the total number of attempts or events. For example, in terms of the average number of attempts across all levels and versions of a game, the success rate shows how often players complete a particular level relative to the total number of attempts for that level. The success rate per version shows that the success rate for version A *(51.45%)* is slightly higher than for version B (*48.55%*). This indicates that version A tends to have a slightly higher success rate than version B, but the difference is small. To see which version has a greater influence on the second course of the game, the success rate was calculated for each version and sequence. It turns out that both versions have a very similar success rate at the beginning. In both versions, Sequence 1 tends to have higher success rates than Sequence 2, which could indicate that the order in which the elements are presented has an influence on success. It is possible that participants are more motivated or better prepared in the first sequence. Interestingly, however, players who first played version B (*33.17%*) and then switched to version A (*19.39%*) had a better second success rate than players who first played version A (*32.32%*) and then switched to version B (*15.12%*). The positive difference between the success rates in both cases indicates that the order in which the versions were played influenced the players' success rate. Players who played the non-gamification version first and then the gamification version tended to achieve a higher success rate compared to those who played the gamification version first and then the non-gamification version. This suggests that the introduction of gamification after the non-gamification version positively influences the game experience and possibly leads to a higher success rate, as the integration of gamification elements in later phases of the learning process provides an additional incentive and can increase players' motivation and skill acquisition. To get information about the level structure, the success rate per version and sequence per level was also analyzed.

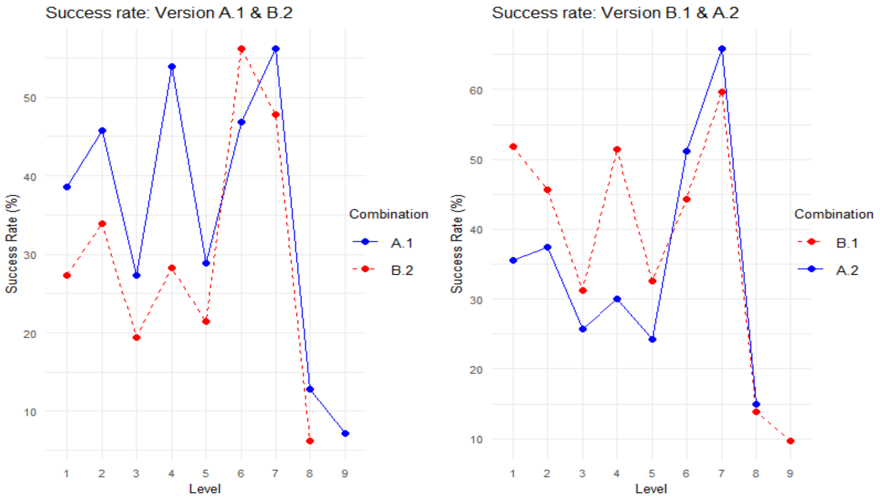

Figure 3: Comparison of success rates between different versions and sequences (left: students who played version A and then version B; right: students who played version B and then version A).

The success rates vary for both versions and sequences, with some levels having higher success rates than others (Figure 3). However, there does not appear to be a clear trend indicating that one particular version or sequence has a consistently higher or lower success rate than the other. It is important to note, however, that based on the previous findings, players at the higher levels have a better success rate on the second playthrough. This could indicate that players improve their skills and strategies throughout the game, regardless of version or sequence. However, the improvement could also be because players are more familiar with the game mechanics in the second playthrough and therefore have a higher success rate.

Overall, these results suggest that both the level structure and the order in which the versions are played are important factors in players' success rates. However, there is no clear evidence that any particular version or sequence generally leads to a higher success rate.

4.4 Attempts

Analyzing the average number of attempts across the different levels and versions provides insight into participants' behavior in relation to gamification and non-gamification approaches, as well as the influence of skill acquisition. There is some variation in the average number of attempts between versions A (gamification) and B (non-gamification) across the different levels. However, there is no clear trend as to whether gamification or non-gamification leads to fewer attempts. The results show that the average number of attempts generally increases as the level increases, regardless of whether gamification or non-gamification sequences are involved. However, it can be observed that the average number of attempts decreases in the middle of the game, especially in levels 6 and 7 (Figure 4, on the left). This indicates that the players gained experience over the course of the game and were able to cope well with the increasing difficulty of the levels. Only in levels 8 and 9 did the average number of attempts increase as the difficulty of the level environment increased. In terms of skill acquisition, this could mean that players understood the physical skills well up to level 7 but showed skill deficits from level 8 onwards. This suggests that factors other than game mechanics could influence the number of attempts. The analysis by version, sequence and level grouping showed that the average number of attempts in the gamified sequences was generally lower than in the non-gamified sequences *(Version A, Sequence 1: M = 4.91, Sequence 2: M = 5.15; Version B, Sequence 1: M = 4.83, Sequence 2: M = 5.10)* (Figure 4, on the right).

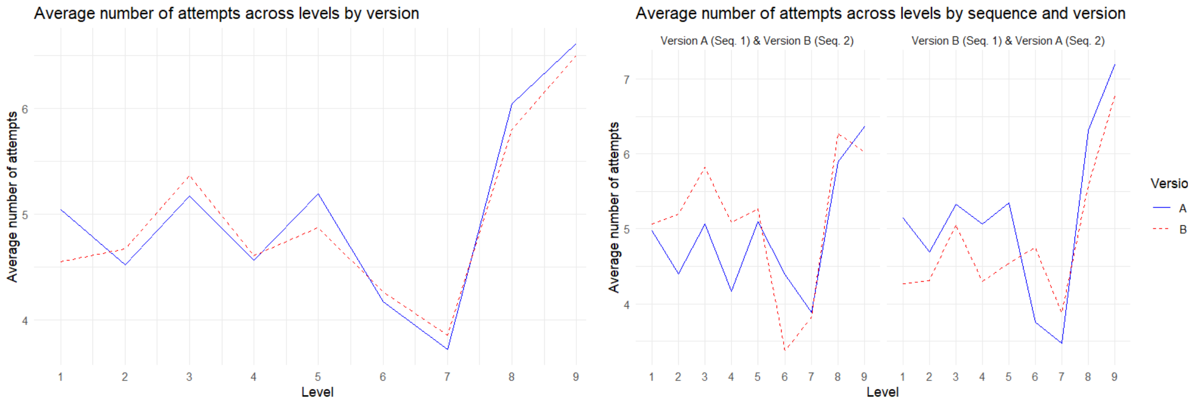

Figure 4: Average number of attempts by Version A and B, sorted by sequence and level (left: students who first played Version A then Version B; right: students who first played Version B then Version A).

This indicates that the integration of gamification elements can help to increase user engagement and motivate them to focus more on the tasks. However, the Wilcoxon-Mann-Whitney test showed no significant difference in the average number of trials between the two versions *(z = 808061, p = 0.267)*, indicating that there was no clear preference for one version over the other. The Kruskal-Wallis test for sequences within each version also revealed no significant differences *(Version A: Chi-square(1) = 0.318, p = .0.573; Version B: Chi-square(1) = 0.70 p = 0.402)*, suggesting that the order in which participants experienced the gamified and non-gamified approaches did not have a significant impact on the number of attempts. Overall, the results suggest that the integration of gamification elements can help increase user engagement, while the number of attempts over the course of the game increases as the difficulty of the levels increases.

5. Discussion

The results of our study provide important insights into the dynamics between gamification elements, level structure, and skill acquisition, particularly in the context of physics learning through interactive gameplay. The integration of elements such as scoring systems and competitions influences player engagement and can increase their motivation, which in turn influences learning success (Smiderle et al., 2020). Our hypotheses, centered around the impact of gamification on engagement, learning outcomes, and the optimal design of game structures, are supported and nuanced by the observed data. H1 posited that participants using the gamified version of the "Basketball Physics Challenge" would exhibit higher engagement levels and motivation compared to those using the non-gamified version. In summary, our hypothesis (H1) was largely supported. Our analysis showed that integrating gamification elements into the learning context proved to be an effective way to increase learner interest and engagement, which ultimately led to better learning outcomes. These results, though, are in line with previous literature suggesting that gamification elements can increase user motivation (Song & Yao, 2022). However, the difference in our results was not statistically significant. H2 aimed to assess whether the gamified version leads to a greater improvement in learning outcomes related to force and motion. Our results suggest that while both versions facilitated skill development over time, there was no substantial difference between them in terms of learning outcomes. This finding contrasts with some previous research suggesting that gamification can lead to improved learning performance (Buckley & Doyle (2014); (Chans & Castro, 2021). However, it highlights the importance of considering various factors, such as individual differences and game design, in determining the impact of gamification on learning. H3 explored the optimal number of game levels to maximize skill acquisition without causing disengagement or cognitive overload. Our analysis revealed that as the level difficulty increased, so did the average number of attempts, suggesting a potential threshold beyond which players may experience challenges in skill acquisition. While success rates improved at higher levels, indicating skill progression, it's important to balance level difficulty to keep players engaged without overwhelming them. This is consistent with previous studies emphasizing the importance of adaptive difficulty levels in maintaining player motivation (Hallifax et al., 2019). Regarding the optimal number of levels and game elements, we found that a good balance is crucial. Too many levels or game elements can overwhelm or disengage learners, while too few may not be enough to maintain engagement. An appropriate challenge that continually motivates the learner is critical to the success of the gamification strategy. H4 and H5 examined the differential impact of specific game elements and their sequencing on learning outcomes and engagement. The results of our research showed that the sequencing of specific gamification elements can have a significant impact on learning motivation. The order in which rewards, challenges, and progress indicators are presented can influence learner interest and engagement. Careful planning and coordination of these elements is therefore important to achieve the desired results. Notably, introducing gamification elements early in the sequence tended to lead to better results, highlighting the importance of strategic implementation of gamification in educational contexts.

Overall, the results show that level structure and the integration of gamification elements can have a significant impact on the game experience and skill acquisition in educational games. A well-designed level structure that provides increasing complexity of challenges can help deepen players' understanding of physics concepts. The integration of gamification elements can increase player engagement and motivation, which in turn can have a positive impact on learning success (Mekler et al., 2017). By embedding the learning content in an interactive game environment and the strategic use of gamification, the project aims to provide new insights into the effective design of educational games. These findings can help increase engagement and learning efficiency in educational contexts, which is particularly important when teaching complex scientific content. The results of the study should provide well-founded recommendations for the development and implementation of educational games that can be used in both school and non-school learning environments.

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