EPiC Series in Built Environment
Volume 7, 2026, Pages 395–404
Proceedings of Associated Schools of Construction 62nd Annual International Conference

Leveraging Digital Games for Construction and Engineering Education: Development of a Beam Design Learning Tool

Busra Yucel[1], Alper Turgut[2], Salman Azhar[1], Jose Henriques[2]
[1]Auburn University, [2]Hasselt University

Traditional structural design education often struggles to engage students in applying abstract engineering concepts to practical problem-solving contexts. This study presents a proof of concept of a gamified learning tool for timber beam design, integrating constructivist principles and structural design standards into an interactive educational experience. The tool incorporates seven core gamification elements, problem-solving, goal clarity, adaptive challenges, user control, feedback, uncertainty, and sensory design, to enhance engagement and learning outcomes. The present work focuses on the design rationale, implementation, and formative evaluation of the prototype rather than on summative measurement of learning gains. Preliminary user feedback and expert review indicate that the tool is computationally robust, pedagogically aligned, and perceived as useful for practicing structural design procedures. As proof of concept, this study demonstrates the feasibility of embedding constructivist game mechanics within technically rigorous structural engineering workflows and establishes a foundation for ongoing research involving large-scale classroom deployment and controlled assessment of learning outcomes.

Keywords: Serious games, Constructivism, Timber beams, Structural design, Self-regulated learning

Introduction

Digital games are interactive programs that allow one or multiple players to follow specific rules and receive feedback that directs them to specific outcomes. For decades, numerous computer games have been developed following the first computer-based game developed by Steve Russell at the Massachusetts Institute of Technology in 1962 (Brandom, 2013). These games had a broad range of topics and audiences, from sports simulation to role-playing. Since digital games often involve problem-solving, interaction, active learning, and discovery (Seraji & Olsadat Musavi, 2023), it has been gaining increasing popularity as an education tool. By combining entertainment with specific learning outcomes, digital games aim to help players achieve learning goals through various educational and recreational scenarios (Denham & Guyotte, 2018). Due to their high potential for social and mental development, games have been used for educational purposes for decades (Amory et al., 1999; Paraskeva et al., 2010).

Like any learning environment, such educational games are designed based on specific learning theories such as behaviorism, cognitivism, and constructivism. Especially, the constructivist approach can enable players to define their challenges, offer tools to develop their solutions, and incorporate a system for receiving feedback (Plass et al., 2015). Previous studies evaluated the best-selling games designed for 7-12-year-olds and showed that 84% of the game content was developed based on constructivist learning principles. Even though mainstream games don't have educational purposes, they are built on constructivist approaches (Seraji & Olsadat Musavi, 2023). Accordingly, constructivist approaches directly influence the popularity of video games, alongside other game mechanics such as graphics, which motivate and attract more players.

Given the complex nature of higher education content, tools such as video games and online platforms can be critical for both teachers and students to enhance the effectiveness of learning. This is particularly true in fields like civil engineering and construction, where applying interactive and experiential methods can be challenging. Games provide interactive and experiential learning experiences, which are particularly effective for complex and practical disciplines like civil engineering and construction (Cook-Chennault et al., 2022; Dinis et al., 2017; Ebner & Holzinger, 2007). They allow students to experiment, visualize concepts, and apply knowledge in a simulated environment. Despite the potential that serious games have for civil and construction engineering students, existing research and the games available online do not focus on structural design and do not incorporate constructivist learning approaches.

Accordingly, this paper presents the proof-of-concept design and prototype implementation of a gamified learning tool for Eurocode-based timber beam design. The study explores how constructivist learning principles and gamification elements can be embedded within a structural design workflow and evaluates the feasibility and perceived usefulness of the tool based on preliminary student feedback. Guided by the literature on constructivist game-based learning, this study addresses the following research question: *"RQ: How can constructivist learning principles and gamification elements be systematically integrated into a Eurocode-based timber beam design workflow in a manner that supports usability, standards compliance, and perceived learning effectiveness?"* The contribution of this paper is the development of a gamified learning framework for Eurocode-based timber design, with future extensions planned to integrate U.S. design standards.

Research Background and Literature Review

Constructivism was defined by the Association for Supervision and Curriculum Development (ASCD) as "*an approach to teaching based on how people learn, emphasizing that learners construct knowledge through exploration and active engagement rather than passive reception. It favors hands-on activities over textbooks and focuses on themes, concepts, and their connections rather than isolated facts."* The constructivist educational approach that encourages students to think and actively engage with problems aligns exceptionally well with digital games, as games naturally embody the core constructivist belief that learners build knowledge through exploration and experience rather than passive reception.

In educational literature, games designed with a primary purpose other than pure entertainment, such as education, training, or behavior change, are called "serious games" (Lamb, 2024). Serious games aim to help learners acquire knowledge while motivating and entertaining them. Accordingly, elements such as visuals and storytelling should be integrated in accordance with educational principles. Seraji and Olsadat Musavi (2023) conducted a systematic mixed-studies review and identified four core factors defining the effectiveness of serious games developed on constructivist learning principles: (i) interaction, (ii) problem-solving, (iii) activity-centeredness, and (iv) discovery.

Interaction refers to allowing players to engage with the game's rules, elements, and other players, and to receive feedback. Problem-solving, on the other hand, refers to a game's inclusion of challenging, problem-centered situations that encourage players to find solutions and create knowledge, often through real-world problems (Sánchez & Olivares, 2011). Activity-centeredness highlights the need for active engagement from players, moving beyond passive information reception to active participation in tasks and activities within the game. Lastly, discovery emphasizes self-directed exploration within the game environment, allowing players to uncover information and relationships on their own (Hung, 2015; Seraji & Olsadat Musavi, 2023). Together, these four factors demonstrate how effectively a serious game can facilitate active knowledge construction, critical thinking, and engagement, hallmarks of constructivist learning environments (Seraji & Olsadat Musavi, 2023).

Serious games have been increasingly used in AEC education due to their high potential for constructivist learning. Especially after the shift to online education during the COVID-19 pandemic, virtual environments have gained greater importance in higher education (Yücel et al., 2024).Moreover, in addition to digital platforms, the construction education literature also documents a rich tradition of in-person, physical, and tabletop games used for teaching concepts such as collaboration, lean production, and process improvement (Rybkowski et al., 2021). Several studies have developed tools to support teaching engineering, each with a different focus. Taillandier and Adam (2018), for instance, designed a course at the University of Bordeaux to teach civil engineering students about natural hazards and territorial risk management. Their serious game, SPIRIT, aimed to help students learn concepts critical to their curriculum, such as territorial risk, vulnerability, resilience, and balanced management. The game's model was fully implemented in an open-source multi-agent geographical simulation platform called GAMA.

Similarly, Yücel et al. (2024) developed a generic modular virtual laboratory framework that enables engineers, game designers, and developers to create lab experiments as serious games without requiring any coding experience. The framework was designed with modularity at its core, allowing easy future extensions and specific enhancements to lab experiments. This is an important contribution to constructivist teaching, as Plass et al. (2015) emphasized that constructivist game-based learning should allow for defining different challenges. In their study, Yücel et al. (2024) tested the proposed framework through a case study tailored for a civil engineering soil mechanics course. The results showed that the game received positive feedback from students, demonstrating its potential for interactive virtual labs. Instructors also evaluated the virtual labs positively, with most rating their effectiveness in achieving teaching goals as "good to excellent".

Serious games that incorporate game mechanics and storytelling can increase engagement, motivation, and retention, making them valuable tools for skill development in various fields (Naul & Liu, 2020). They provide a constructivist learning environment where learners actively build knowledge through exploration, experimentation, and problem-solving. However, despite the growing interest in serious games for engineering education, a notable gap remains in the literature regarding the development of game-based learning tools specifically designed to teach timber structural design. Existing studies rarely integrate storytelling elements with the technical complexity of structural engineering concepts. This gap presents an opportunity to develop innovative educational games that not only convey engineering principles effectively but also enhance learner engagement and comprehension through narrative-driven experiences.

Methodology

This study adopts a proof-of-concept, design-based research approach in which educational theory, content requirements, and iterative prototyping informed the development of the tool. The primary goal is to translate key concepts of structural design into an interactive, accessible learning experience. The methodological emphasis is therefore on the design process, implementation, and formative evaluation of the prototype rather than on summative assessment of learning gains. For practicality and simplicity, the scope was defined around the fundamentals of timber beam design, focusing on essential calculation steps commonly covered in undergraduate building structures courses. These included identifying the tributary width, determining the design load, and calculating the maximum moment and shear forces acting on the beam. Once these modules were established, the game structure was designed to align with the targeted learning outcomes. The rules, feedback mechanisms, and visual elements were carefully prepared to guide players through the design process. Visual cues, such as load diagrams, simplified floor plans, and factor indicators, were integrated to reinforce theoretical concepts with immediate visual feedback, enhancing both understanding and engagement.

The demo was developed using HTML and JavaScript, allowing for browser-based accessibility and interactive functionality. All the files are hosted on Github and any person with the link directly has access to the game without downloading any files (see https://yucelbusra.github.io/structural-engineer-game/). Throughout the development process, the author team held monthly meetings to perform technical testing, identify usability issues, and conduct iterative debugging. Feedback from these sessions informed continuous refinements to both interface design and computational logic, ensuring pedagogical accuracy and reliability. Figure 1 illustrates the overall research and development workflow, from defining learning objectives and design logic to implementation and evaluation.

Regarding the constructivist learning approach, we considered several core elements for well-designed games during the game development phase. Shute and Ke (2012) synthesized and presented seven core components of well-designed constructivist games: interactive problem-solving, specific goals/rules, adaptive challenges, control, ongoing feedback, uncertainty, and sensory stimuli. We incorporated these elements into our game design by integrating one or more of them within each module. Table 1 presents these core elements and explains how each feature was addressed in the game development.

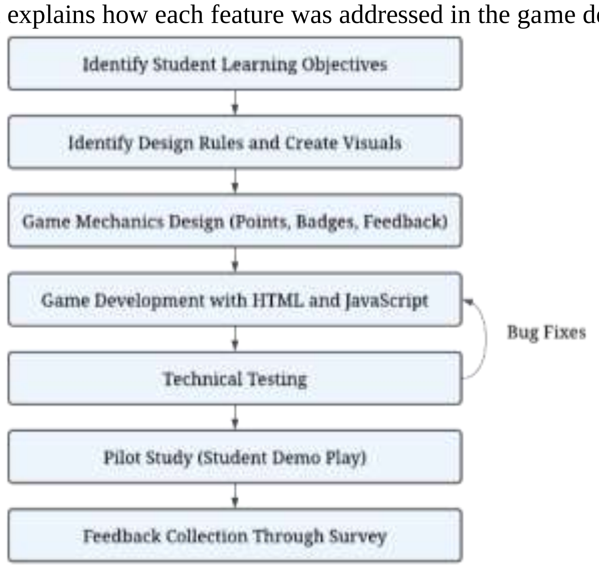


Figure 1. Research and development workflow.

Table 1. Core components of constructivist educational games.

Core Element	Definition	Representation in Game
Interactive problem solving	Continuous interaction with the game, solving a series of challenges or quests	Multi-step workflow
Specific goals/rules	Clear rules and objectives guide players' actions and maintain focus	Clear objectives with explicit instructions
Adaptive challenge	Adjust difficulty to match players' skills	Hints increase after failed attempts. Points deducted for errors
Control	Ability to influence gameplay, the environment, and the learning experience	Players choose beam count, dimensions, load combinations, and limit states (ULS/SLS). Page navigation
Ongoing feedback	Timely, explicit or implicit feedback supports player learning	Visual feedback, color-coded messages, sound effects, and points display
Uncertainty	Elements of unpredictability sustain suspense and engagement	Progressive revelation, badges unlocking
Sensory stimuli	Visuals, sounds, and narratives stimulate players' senses and interest	Visual canvas drawings, load visualizations, combined load images, sound effects

These steps were implemented iteratively in collaboration with the author team, which included two professors and two graduate teaching assistants from the Civil Engineering and Building Construction departments, to validate the timber beam design demo. The iterative process ensured that both the technical accuracy of the design procedures and the educational usability of the demo were verified through multiple testing and feedback cycles. Additionally, the game demo was evaluated by two undergraduate students enrolled in the Structural Engineering program at Hasselt University, providing insights for the continued development of the full version of the tool.

Following this validation phase, the results section presents the key findings from the implementation, focusing on user interaction outcomes, accuracy of the computational framework, and the overall effectiveness of the demo as a teaching tool.

Findings and Discussion

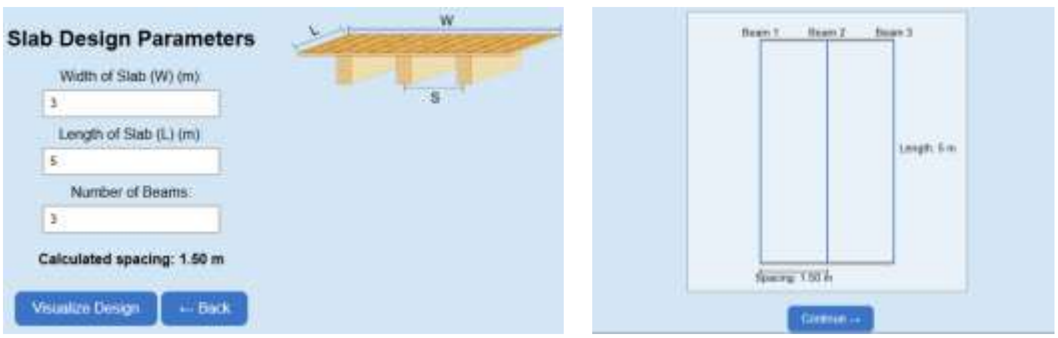
The implementation and testing of the gamified timber beam design tool revealed several key findings across technical performance, educational effectiveness, and user engagement dimensions. This section presents the results organized by the core gamification elements and their manifestation in the structural engineering context.

Interactive Problem Solving, Goal Structure, and Rule Clarity

The game tool includes several items that increase the interactivity of players with the interface. First, it implements a sequential problem-solving workflow that guides users through the complete timber beam design process. As shown in Figure 2, the six-stage progression mirrored authentic engineering practice while maintaining pedagogical scaffolding. Clear learning objectives were established at each stage through explicit instructions and visual progress indicators. The progress can be followed on this bar through the color change of completed steps. Accordingly, the progress bar provides users with both orientation within the workflow and a sense of advancement.

Figure 2. Progress bar showing the workflow

The interactive canvas-based visualization allows users to input design parameters (Figure 3a) and immediately observe the geometric representation of the player's slab and beam configuration (Figure 3b). This real-time feedback mechanism proves effective in helping students understand the relationship between numerical inputs (width, length, beam count) and physical spacing calculations. Also, this allows players to create different design scenarios having various slab dimensions and beam numbers.



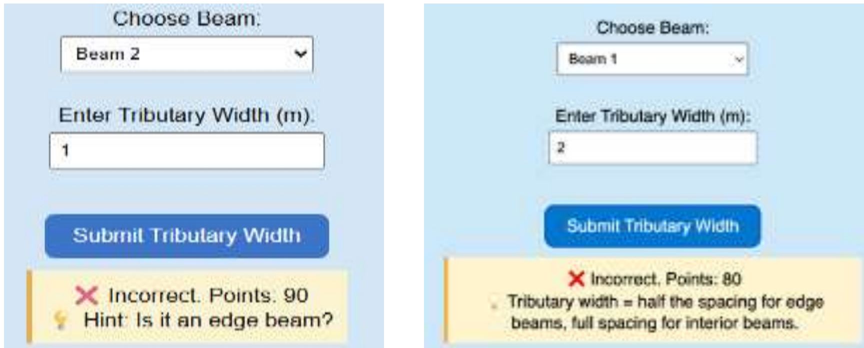
a) Value input for slab dimensions b) Floor plan illustrated

Figure 3. Example for interactivity for floor plan drawing

The Eurocode-based calculation rules were embedded within the interface through structured input forms and validation mechanisms. The compact combination table (Figure A) for selecting load combinations, partial factors (γG, γQ), and combination factors (ψ_0, ψ_1, ψ_2) systematically guided users through the complex decision-making process required for limit state design. Moreover, hint buttons were inserted for players to refer to design tables for γ and ψ selection.

Adaptive Challenge Mechanisms, Feedback, and Sensory Engagement

The tool implements three primary adaptive mechanisms: progressive hint revelation, attempt-based feedback variation, and tolerance-based scoring. Figure 4 shows the hints for the tributary width calculation, escalated from general prompts (Figure 4a) to specific guidance (Figure 4b), based on the attempt count. Also, the point deduction system (−10 points per incorrect attempt) created consequences for errors while maintaining engagement. This scoring structure effectively balanced challenge with achievability. Feedback adaptation was observed through the selection of visual responses (GIFs) and message tone variation. Context-sensitive success messages prevented monotony across multiple attempts while maintaining emotional engagement with the learning process.



a) First error hint b) Second error hint

Figure 4. Feedback message examples showing escalation of hints.

The tool implemented a multi-modal feedback system encompassing visual, textual, auditory, and scoring elements. Immediate validation feedback appeared for all numerical inputs, with color-coded message boxes (green for correct, amber for incorrect) providing clear success/failure signals. The feedback messages included both evaluative content ("☑ Correct!") and explanatory content ("Expected Ed = X.XX kN/m"), supporting both motivation and learning. Figure 5 illustrates feedback to correct the response given in the first trial for the tributary width input.

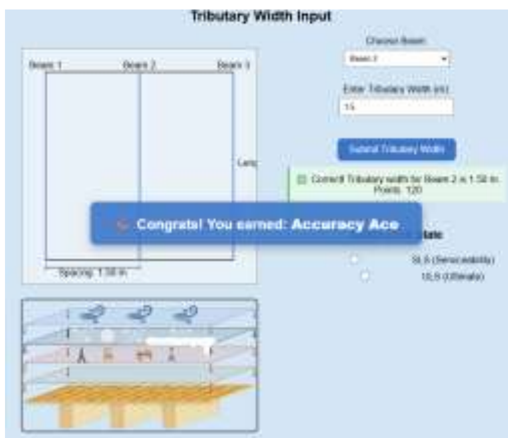
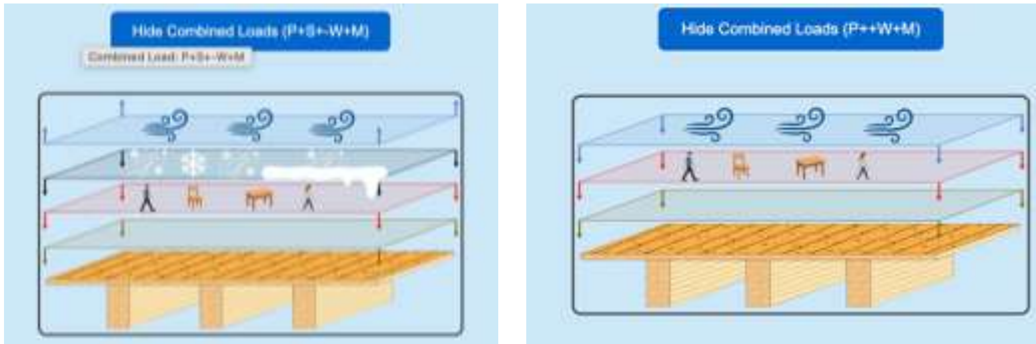


Figure 5. Feedback message example for the correct answer.

Visual design elements included color-coded progress indicators, geometric canvas representations, load diagram illustrations, and animated GIF responses. Canvas resolution optimization through device pixel ratio scaling ensured crisp visualization across different display technologies. The load combination images provided schematic representations of physical phenomena (permanent loads, snow accumulation, wind pressure, mobile loads) that connected abstract numerical inputs to real-world scenarios. Sound effects reinforced visual feedback through distinct audio cues for clicks, successes, errors, and badge unlocks. The canvas-based visualizations provided continuous implicit feedback. As users modified load values, corresponding load diagrams appeared (Figure 6), allowing immediate pattern recognition. In subsequent figures, permanent loads are denoted by P, snow loads by S, wind loads by W, and mobile (live) loads by M.



a) Load combination schematic: P+S-W+M b) Load combination schematic: P+S+M

Figure 6. Schematic representations of load combinations.

Control and Uncertainty

The tool provides users with meaningful control through multiple design parameters, including slab dimensions (width and length), number of beams, load magnitudes (permanent, snow, wind, and live), limit state selection (ULS or SLS), leading action designation, and associated load combinations. Users can review and adjust their inputs before advancing, enabling revision when inconsistencies are detected. However, this control is deliberately bounded by engineering constraints to ensure realism and accuracy. Progression is restricted until validation criteria are satisfied, for instance, a minimum of two beams, positive geometric dimensions, and valid tributary widths. All design calculations are automatically verified against Eurocode formulations to preserve structural correctness, with a margin of error of 0.05 kNm/kN. Figure 7 illustrates the design-check interface that supports these validation processes.

Figure 7. Validation checks for internal forces (M and V).

Besides control elements, the tool also includes uncertainty manifested through three primary mechanisms: hidden badge requirements, progressive screen revelation, and variable feedback content. The badge system displayed locked badges without revealing specific unlock criteria, creating anticipation and discovery opportunities. The progressive disclosure of workflow stages maintains engagement by preventing overwhelming preview of remaining complexity. Users encountered each calculation challenge sequentially, with future steps masked until prerequisite stages were completed. The randomized selection of success messages and failure GIFs introduced micro-level unpredictability that sustained interest across multiple attempts.

Formative Proof-of-Concept Feedback

To support the proof-of-concept objective, the prototype was tested with two structural engineering students who interacted with the full game workflow and completed a brief survey. Their responses indicated that immediate feedback, progressive hints, and visual representations helped them understand design steps, and that the reward system motivated continued engagement. These data are intentionally modest in scope and serve a formative rather than evaluative purpose: they demonstrate usability and perceived value and inform subsequent tool refinement. Future research will incorporate IRB-approved classroom studies and quantitative analysis of learning outcomes.

Conclusion

This paper presents a proof-of-concept gamified learning tool for Eurocode-based timber beam design. The project demonstrates that constructivist learning principles and gamification elements can be systematically embedded within a rigorous structural design workflow. Within the limits of prototype testing, the tool shows strong feasibility, computational accuracy, and positive perceived usefulness. However, the present study does not claim to provide evidence of learning gains; instead, it establishes the conceptual and technical foundation for future research. Ongoing work includes IRB-approved classroom deployment, expansion to additional structural systems and design codes, and controlled studies comparing the game with conventional instructional methods.

Theoretically, the tool demonstrates how constructivist learning principles can be applied to structural design education through interactive digital experiences. It also offers a model for adaptive scaffolding using progressive hints, feedback variation, and tolerance-based scoring. Practically, it benefits students by providing a low-pressure, self-paced learning environment and supports educators with flexible deployment options, from flipped classrooms to exam prep. Its accuracy and compliance with professional standards make it suitable for both academic and early professional use.

However, the current version is limited to simply supported beams with uniform loads and lacks full accessibility features. Broader validation and user studies are still needed. Ongoing development includes expanding structural scenarios, adding difficulty levels, and creating modules for steel and concrete design. Lastly, the current demonstration version, while focused on Eurocode-based timber beam design, establishes a flexible framework that can accommodate multiple design standards and structural systems. The ongoing expansion to include US codes (ASCE 7, NDS, IBC) and additional structural materials (steel, concrete) will enhance the tool's applicability across diverse educational contexts and geographic regions.

References

Amory, A., Naicker, K., Vincent, J., & Adams, C. (1999). The use of computer games as an educational tool: Identification of appropriate game types and game elements. *British Journal of Educational Technology*, *30*(4), 311–321. https://doi.org/10.1111/1467-8535.00121

Brandom, R. (2013). *'Spacewar!' The story of the world's first digital video game*. The Verge. https://www.theverge.com/2013/2/4/3949524/the-story-of-the-worlds-first-digital-video-game

Cook-Chennault, K., Villanueva Alarcón, I., & Jacob, G. (2022). Usefulness of Digital Serious Games in Engineering for Diverse Undergraduate Students. *Education Sciences*, *12*(1), Article 1. https://doi.org/10.3390/educsci12010027

Denham, A. R., & Guyotte, K. W. (2018). Cultivating critical game makers in digital game-based learning: Learning from the arts. *Learning, Media and Technology*, *43*(1), 31–41. https://doi.org/10.1080/17439884.2017.1342655

Dinis, F. M., Guimarães, A. S., Carvalho, B. R., & Poças Martins, J. P. (2017). Virtual and augmented reality game-based applications to civil engineering education. *2017 IEEE Global Engineering Education Conference (EDUCON)*, 1683–1688. https://doi.org/10.1109/EDUCON.2017.7943075

Ebner, M., & Holzinger, A. (2007). Successful implementation of user-centered game based learning in higher education: An example from civil engineering. *Computers & Education*, *49*(3), 873–890. https://doi.org/10.1016/j.compedu.2005.11.026

Hung, W. (2015). Problem-Based Learning: Conception, Practice, and Future. In Y. H. Cho, I. S. Caleon, & M. Kapur (Eds.), *Authentic Problem Solving and Learning in the 21st Century: Perspectives from Singapore and Beyond* (pp. 75–92). Springer. https://doi.org/10.1007/978-981-287-521-1_5

Lamb, R. (2024). Serious Games. In *Oxford Research Encyclopedia of Communication*. https://oxfordre.com/communication/display/10.1093/acrefore/9780190228613.001.0001/acrefore-9780190228613-e-1482

Naul, E., & Liu, M. (2020). Why Story Matters: A Review of Narrative in Serious Games. *Journal of Educational Computing Research*, *58*(3), 687–707. https://doi.org/10.1177/0735633119859904

Paraskeva, F., Mysirlaki, S., & Papagianni, A. (2010). Multiplayer online games as educational tools: Facing new challenges in learning. *Computers & Education*, *54*(2), 498–505. https://doi.org/10.1016/j.compedu.2009.09.001

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of Game-Based Learning. *Educational Psychologist*, *50*(4), 258–283. https://doi.org/10.1080/00461520.2015.1122533

Rybkowski, Z. K., Alves, T. da C. L., & Liu, M. (2021). *The Emergence and Growth of the on-Line Serious Games and Participatory Simulation Group "APLSO."* 269–278. https://iglc.net/Papers/Details/1858

Sánchez, J., & Olivares, R. (2011). Problem solving and collaboration using mobile serious games. *Computers & Education*, *57*(3), 1943–1952. https://doi.org/10.1016/j.compedu.2011.04.012

Seraji, F., & olsadat Musavi, H. (2023). Does applying the principles of constructivism learning add to the popularity of serious games? A systematic mixed studies review. *Entertainment Computing*, *47*, 100585. https://doi.org/10.1016/j.entcom.2023.100585

Shute, V. J., & Ke, F. (2012). Games, Learning, and Assessment. In D. Ifenthaler, D. Eseryel, & X. Ge (Eds.), *Assessment in Game-Based Learning: Foundations, Innovations, and Perspectives* (pp. 43–58). Springer. https://doi.org/10.1007/978-1-4614-3546-4_4

Taillandier, F., & Adam, C. (2018). Games Ready to Use: A Serious Game for Teaching Natural Risk Management. *Simulation & Gaming*, *49*(4), 441–470. https://doi.org/10.1177/1046878118770217

Yücel, F., Sultan Ünal, H., Surer, E., & Huvaj, N. (2024). A Modular Serious Game Development Framework for Virtual Laboratory Courses. *IEEE Transactions on Learning Technologies*, *17*, 966–981. https://doi.org/10.1109/TLT.2024.3349579