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A Gamified Pedagogical Method for Teaching Construction Scheduling through Active Exploration

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Previous studies have convincingly shown that active and collaborative instructions, coupled with effective means to encourage student engagement, invariably lead to better learning outcomes. However, despite significant potentials for experiential learning, standard educational programs in construction engineering and management are rigid systems that offer little opportunity for students to engage in active learning that can help them gain first-hand experience and guide them toward discovering solutions. This study aims to address this need by designing and empirically assessing the performance of a novel gamified pedagogical method that teaches construction scheduling through guided active exploration in a digital game environment. The proposed pedagogical approach and its game are designed based on the constructivism learning theory. A scenario-based interactive game, called *Zebel*, was developed using the Unity game engine. Using a series of pre- and post-assessment instruments, the proposed method was implemented and evaluated in a graduate-level course for construction planning and scheduling to collect empirical data. The outcomes indicated that the proposed pedagogy was able to successfully guide students with no background and prior knowledge in construction scheduling to discover the fundamental concepts and systematic solutions for the problems.

Key Words: Gamified Pedagogy, Active Exploration, Construction Scheduling, Constructivism

Introduction

The history of construction dates back to the Neolithic era (i.e., New Stone Age), roughly from 9000 BC to 5000 BC (Violatti 2018). Many prehistoric structures, including megalithic temples in Malta (from around 3600 BC) and the Egyptian pyramids (from around 2500 BC) are still standing. However, Newton's laws of motion, which laid the foundation for classical mechanics and, consequently, structural analysis, were first published in 1687, only 336 years ago. For thousands of years, structures were built without formal theories that mathematically explain why they stand. The evolution of construction engineering from ancient times to the seventeenth century was mainly based on discoveries through trial and error that helped craftsmen empirically distinguish good design and construction methods from less effective approaches (Abrams 1994). From the seventeenth century, when Newton presented his laws of motion, engineering concepts gradually developed stronger connections with mathematical expressions. The mathematical representation of engineering concepts is the foundation of modern engineering and engineering education. There is no doubt about the necessity of mathematical expression for engineering topics. However, through time, educational programs in many engineering fields, including construction, have evolved into rigid systems that mainly train students to follow specific procedural algorithms for inserting data into well-defined equations and calculating expected outcomes for closed-ended problems. These educational programs offer little opportunity for students to engage in active learning that can help them gain first-hand experience and guide them toward discovering solutions. However, previous studies have convincingly shown that active and collaborative instructions, coupled with effective means to encourage student engagement, invariably lead to better student learning outcomes (Kuh et al. 2011, Weimer 2022). Therefore, recently, designing learning methods based on active exploration has received attention in various fields including construction. The long history of empirical learning in the field of construction engineering shows the significant potential of cognitive development through direct experience and reflection on what works in particular situations (Boothby 2018). Of course, the complex nature of the construction industry in the twenty-first century cannot afford an education through trial and error in the real environment. However, recent advances in computer science can help educators develop virtual environments and game platforms that allow students to explore various scenarios and learn from their experiences. Ilbeigi et al. (2023) conducted a systematic review of more than one hundred studies focused on gamification for construction engineering education. Although they observed a clear upward trend in the number of studies proposing gamified solutions for education and training, they listed a set of potential directions for future studies. One of the potential topics is to use games as facilitator for learning through active exploration. The overarching objective of this study is to design and empirically assess the performance of a novel gamified pedagogical method that teaches construction scheduling through guided active exploration in a digital game environment. More specifically, we examine whether guided active exploration in a digital game environment improves students' ability to discover systematic strategies to solve fundamental problems in construction scheduling. To address this objective, the remainder of this paper is organized as follows. After a brief introduction to gamification in education, we present the methodology, including the design of the gamified approach and assessment strategy. Next, we describe the implementation outcomes. Finally, we summarize the results, discuss the contributions of this study to the body of knowledge, and depict future research directions.

Gamification

Gamification or serious games apply game elements and principles in non-game contexts (Dicheva et al., 2015). If appropriately designed, serious games can provide an interactive environment where users can engage with technical contexts, explore different scenarios, acquire new knowledge, and connect that knowledge to their existing mental models (Deshpande and Huang 2011). The term gamification was coined by Nick Pelling in 2002 and hit the mainstream around 2010 (Pelling 2011). The elements of a gamified system can be categorized into three groups: (1) Dynamics: which defines the big picture aspect of the game and includes elements such as constraints, narratives, progression, and relationships, (2) Mechanics: which defines the processes that drive actions forward and includes elements such as challenges, chance, competition, cooperation, feedback, resource acquisition, rewards, transactions, turns, and win states, and (3) Components: that shows specific instantiations of mechanics and dynamics and includes elements such as points, quests, achievements, badges, avatars, and virtual goods (Werbach and Hunter 2012).

Methodology

The envisioned methodology in this study revolves around two components: (1) the game and (2) the assessment strategy to evaluate the effectiveness of the proposed gamified pedagogy. In this section, first, we introduce the game and its characteristics. Next, we present the assessment instruments and empirical data collection strategy.

Zebel: An Interactive Game for Construction Scheduling

To address the objective of this study, we designed and developed an online game called *Zebel*. The game is a mobile/tablet application that provides an interactive digital environment in which users try to solve fundamental problems in the domain of construction planning and scheduling presented in realistic scenarios through guided active explorations. Figure 1 shows a snapshot of the game. The scenario-based problems facilitate sense-making and engage students in understanding, analyzing, and solving open-ended problems in that field. During the active explorations to solve these fundamental problems, the users are exposed to fundamental engineering problems and try to discover systematic solutions to solve them. The game and the proposed gamified pedagogy are designed based on the Constructivism learning theory.

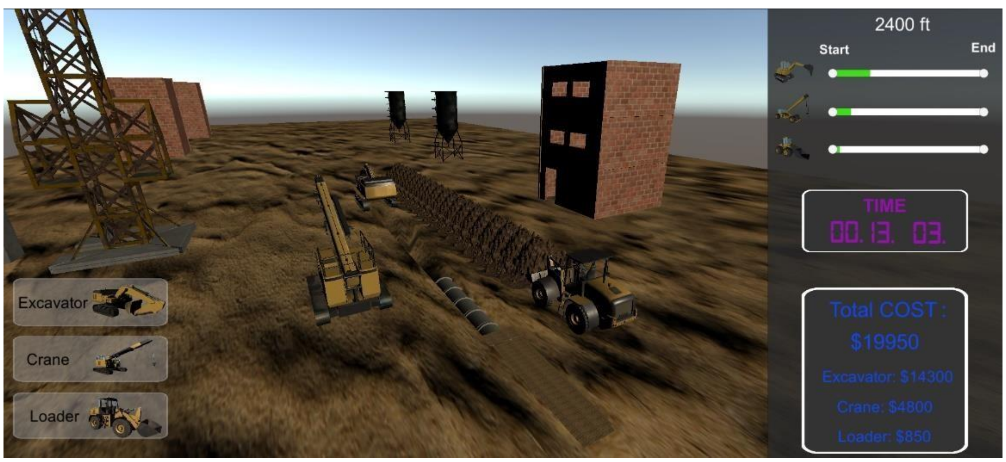

Figure 1: A snapshot of the Zebel game

Constructivism Theoretical Framework

Constructivism learning theory was created based on the theory of cognitive development by Piaget (1952). A long list of researchers including Bruner (1966), Ausubel and Robinson (1969), and Maturana (2006) contributed to this theory and made it the most prevalent variant of cognitivism (Tobias 2010). This learning theory assumes that knowledge is constructed by learners as they attempt to make sense of their observations (Driscoll 2000). The focus of constructivism is on knowledge construction rather than knowledge transmission (Sheppard et al. 2009). The principle of constructivism is an individualized representation of knowledge based on active exploration and learning by interaction, in which learners build on their own individual experiences when they uncover an inconsistency between their current knowledge representation and their new experience (Tobias 2010). The constructivist view of learning has been embraced by the gamification world (Driscoll 2000). The proposed gamified approach in this project is guided by a constructivist framework developed specifically for learning through gamification (Newstetter and Svinicki 2015). This learning framework is based on the following six essentials (Figure 2):

1. **Modeling**: This involves taking advantage of the learners' prior knowledge and providing them with background knowledge related to the learning objectives of the game. The goal of modeling is to enable students to build a conceptual model of the process required to attain the game's learning objectives.
2. **Reflection**: This involves the process by which the learners logically organize their thoughts and connect their preliminary ideas to separate the more important presumptions from less important ones. The modeling and the reflection phases help learners form their personal synthesis of knowledge that initiates the process of strategy formation.
3. **Strategy Formation**: This involves the learners' efforts to form appropriate playing strategies to solve the problems the game provides.
4. **Scaffolded Exploration**: This involves the learners' exploration of the scaffolded game world, where they perceive the impacts and consequences of their actions through various game elements. The aim is to guide the learners to a mode of problem-solving on their own through the support that the game provides as they carry out different activities.
5. **Debriefing**: This involves a description of events that occurred in the game, an analysis of why they occurred, and the discussion of mistakes and corrective actions by learners. Debriefing is a fundamental link between game experiences and learning that helps learners deconstruct the activity and then connect it to their mental models.
6. **Articulation**: This involves students' sharing of their game experience and acquired knowledge to progress toward collective goals of understanding. Articulation encourages the social negotiation of meaning that is a primary means of solving problems, building personal knowledge, establishing an identity, and most other functions performed in teams.

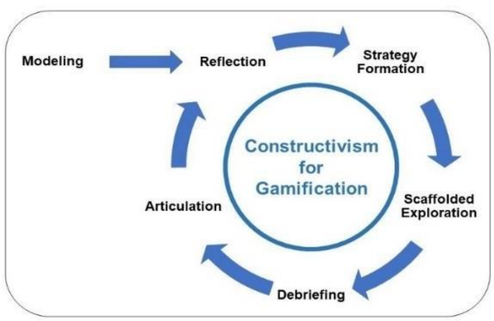

Figure 2: Constructivism framework for gamification

The game has been designed based on these six essentials. Regarding the Modeling process, students who will use the game have some levels of understanding about construction projects. The game also uses animated demonstration videos to provide background information about the construction scenarios. For example, in each chapter of the game, a short animation introduces the problem, objectives, tasks, and resources, including different types of heavy equipment involved in that scenario-based problem. For the Reflection, students' prior knowledge and the design of the game and its features will give students ideas about the objectives of the game, how to start it, and how to proceed. For Strategy Formation, after understanding the game and its features, students will start thinking about how to use available resources to solve the problem. For example, what type and how many pieces of each type of equipment are needed to successfully solve the problem, considering limitations such as available budget and time? Regarding the Scaffolded Exploration, in the game, students are able to perceive the consequences of their actions constantly through game elements such as points and resource utilization. Depending on the complexity of a problem and the student's performance, the game may provide them with some hints as well. Eventually, based on the students' progress, feedback from the game, and new information that is added to the student's cognitive organization, the students can adjust their actions and update their strategies. For Debriefing, depending on the scenario of the game and students' performance, Zebel sometimes prompts users to explain their observations, outcomes of their decisions, and strategies to solve the problem. Students will be asked to type their responses in a pop-up box. Finally, for the Articulation step, the game platform provides an online forum where students interface with their peers and share their ideas and findings. The forum also allows students to ask questions and discuss each other's comments and ideas.

Design of the Game

The first chapter of the game, which is the focus of this study, concentrates on the Critical Path Method (CPM) for learners with no prior knowledge and experience in scheduling. CPM is the most common method of scheduling in construction projects. It determines the order of activities and their start and finish times based on their logical dependencies and timing flexibility due to parallel paths through the network of activities. The timing flexibility in an activity, also known as float or slack, is an essential concept in understanding how the CPM works and prioritizes activities in response to limited resources. The first chapter of the game aims to direct students to discover this concept and its application in scheduling a construction project with limited resources through active exploration.

This part of the game provides the students with a scenario in which they need to schedule a set of heavy construction activities in two adjacent sites, i.e., East and West sites. Figure 3 shows the demo of the game. Figure 4 shows a snapshot of the gameplay. The East side has more activities with longer durations compared to the West side. The activities on both sides share a limited number of heavy equipment (e.g., dozer, grader). In some cases, the user needs to determine which activity should have priority to get the equipment and which ones should be postponed while finishing the entire project (i.e., both East and West side) in the shortest possible time. This scenario aims to guide the students to discover three fundamental facts: 1) not all activities have the same level of criticality in terms of being done as soon as possible, 2) critical activities form the longest path in the network of activities, 3) non-critical activities can be delayed to some extent without affecting the completion time of the project, and 4) delaying non-critical activities can be a solution to address the issue of limited resources in a project.

Figure 3: Demo of the game

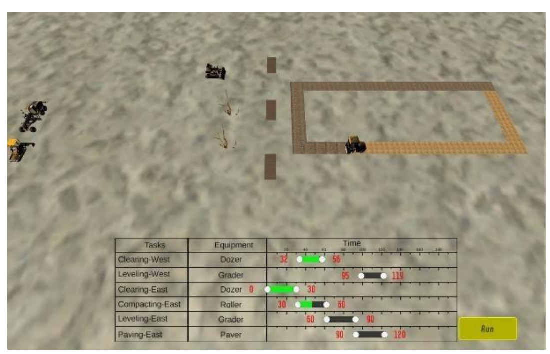

Figure 4: Snapshot of the game play

While playing, after learning about the tasks, equipment, and constraints of the game through a demo, the students will plan a preliminary strategy and guess a start time for each activity, observe the outcomes of their decisions, receive feedback from the game, adjust their strategy, and keep trying until they achieve the goal. They are also required to explain their observations and strategies through the game's debriefing mechanism. Particularly, when a user achieves the goal, the debriefing mechanism will ask the user to come up with a systematic approach to solve this type of problem (Figure 5). After recording the response, the game shows a diagram highlighting the floats in each non-critical activity in the game without any explicit explanation (Figure 6) and repeats the question to check whether the users change their proposed strategy after seeing the diagram.

The Zebel game was created using the Unity game development platform. Unity is a cloud-based game development engine that provides a wide range of services, including a software development kit (SDK), an application programming interface (API), a series of game object libraries, plugins, and predefined functionalities. For the game's debriefing and articulation mechanisms, a cloud-based application was developed to collect user and usage information using a RESTful web service utilizing node JS on Firebase, a Google cloud solution platform. Upon completion of each game, either successfully or by running out of time, the user's activity log and other relevant information will be decoded into a JSON document and submitted to the backend over the Internet. This data, along with user information, is saved into a NoSQL database to be post-processed.

After the successful completion of the first scenario and recording students' inputs, the game provides two relatively more complicated scenarios to expose the students to different consequences of delaying critical activities versus non-critical ones. Finally, the game will ask students to determine critical activities in this project. Right after finishing the game, students have access to the online articulation platform to share their experiences and discuss their strategies together.

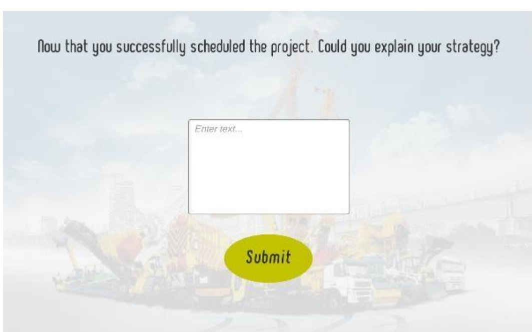

Figure 5: Debriefing mechanism

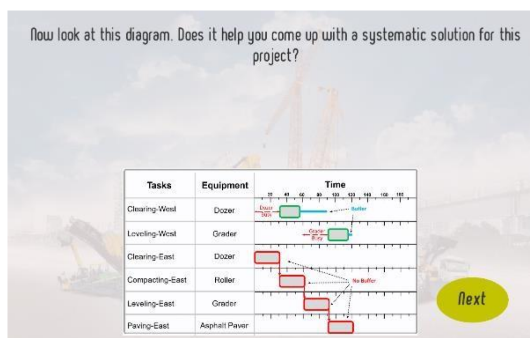

Figure 6: Providing hints

Assessment Instruments

The effectiveness of the proposed gamified pedagogical approach is assessed through four instruments: 1) a prior knowledge survey, 2) a benchmark exam, 3) a game assignment, and 4) a post-game exam. The prior knowledge survey, administered in the first session of the class, aims to identify students who have had exposure to standard ways to solve these problems. If some students have considerable prior knowledge of the target topics, their data are excluded from the assessment analyses. The benchmark exam, conducted in the first session of the class, aims to evaluate students' understanding of the fundamental concepts in scheduling, such as float. The game assignment requires students to use and successfully finish the Zebel game. The game platform records all students' inputs and decisions in log files. Analyzing the log files shows how students set their strategies and update them throughout the game. Finally, the post-game exam, administered a week after the game assignment, is designed to align with the benchmark exam to evaluate students' progress in the understanding of the fundamental concepts after their experience with the game.

Empirical Data Collection

The proposed gamified pedagogical method was implemented in a graduate-level course titled *CM-529: Construction Planning and Scheduling* in the Department of Civil, Environmental, and Ocean Engineering (CEOE) at Stevens Institute of Technology in Fall 2022. The Zebel game served as a formal teaching tool. Forty students registered for the course during that semester. As this project seeks to understand personal information about human subjects, including students' individual perceptions, Institutional Review Board (IRB) requirements and approval were secured before conducting the study. Consent forms were administered on the first day of class, and the students were informed that some of the classroom activities and assignments would be monitored as part of a research project. Students had the opportunity to opt-out, with no impact on their grades, in which case their assignments would be excluded from the research findings. All 40 students agreed to participate in this study. The results of the prior knowledge survey indicated that 10 students had some level of familiarity with the fundamentals of CPM. Their game data was excluded from the analysis process in this study. The students worked on the game assignment in the second week of the class before any introduction to CPM and its fundamental concepts, including float and using it to address resource allocation problems in parallel chains of activities.

Analysis and Results

The recorded data indicated that 27 out of the 30 students with no prior knowledge of CPM worked on the assignment and submitted it before the deadline. The average number of trials to accomplish the game was 4.51, with a minimum of 1 and a maximum of 17 tries. The recorded log files indicate that students tend to schedule everything as soon as possible and gradually learn that they have to delay some of them to manage their resources. Although the demo of the game aimed to explain the scenario of the project, a considerable number of students made some mistakes in setting the activities in a logical order (e.g., clearing the site by a dozer should proceed with leveling the site by a grader) in their early trials. More specifically, 36% of the generated error messages to guide students to fix their strategies were related to the order of the activities. In total, 21 students received this message, but all of them were able to fix the issue in the following rounds. In addition, 13% of the error messages were related to overlapping activities on one side of the project. As noted before, the demonstration of the scenario asks students not to overlap activities on one side of the project for the sake of simplicity. However, they can overlap activities from one side of the project to those on the other side. Like the error related to the logical order of the activities, this error message mostly happened in the early rounds of students' trials.

Regarding the limited resource issue, 27% of the error messages reminded students that they have only one piece of equipment for each type, but their current schedule needs at least one type of equipment on both sides at the same time. Finding a solution to address this issue is the main learning objective of the proposed gamified pedagogy. All students were able to find the solution and solve this problem by postponing the non-critical activities on the west side of the project. Finally, 24% of the generated error messages informed the students that their schedule was correct in terms of the order of the activities and addressing the resource allocation problem; however, the total duration of the project could be shorter.

The students' inputs in the debriefing mechanism of the game asking them to describe their strategy indicate that throughout the game, they gradually noticed that not all activities in a project necessarily have the same level of time sensitivity and they could be postponed intentionally to address the resource allocation problem and assign the limited resources to the activities that are more critical to be done as soon as possible for minimizing the total duration of the project. The results also indicate that students understood that the flexibility (i.e., float) in the start time of a non-critical activity is limited, and they may become critical after a certain amount of delay. Finally, the strategies described by the students showed that they were able to understand that the floats (i.e., flexibility in the timing of some activities) are created because of the parallel chains of activities. In the last part of the game, students were asked to list the critical activities in the project, and more than half of them (i.e., 15 out of 27) were able to completely identify the critical activities in the project. Immediately upon completing the game assignment, students had access to the articulation platform to share their experiences and discuss their strategies. In total, 30 comments were submitted by the students, and they engaged in discussions. All comments were positive.

In the following session after the game assignment, the post-game exam was administered. The questions in the post-game exam were aligned with the questions in the benchmark exam. All the 27 students who did not show any indication of familiarity with CPM and its fundamental concepts, such as float, were able to answer the post-game questions correctly. "*Doing an assignment by playing a game is the most unique and interactive way of learning the subject content I have ever done,*" one of the students noted on the platform. "*This way of teaching does stay in the mind for a longer period of time than regular teaching*" another student commented. "*Although this evaluation is presented in the form of a simple interactive game, it still presents and demonstrates the real-world problems one will encounter as a project manager/construction manager in the field*" one of the students with professional experience in construction scheduling noted. In addition, many students engaged in detailed discussions about their strategies and how they realized the correct solution.

Conclusion

In this study, a novel gamified pedagogical method was designed, and its effectiveness on students' ability to discover systematic solutions for fundamental construction scheduling problems was empirically assessed. The proposed pedagogical method and its game were developed based on the constructivism learning theory. The empirical data collected through pre- and post-assessment instruments, in addition to recorded log files, indicate that the proposed gamified method was able to introduce the students to fundamental concepts in CPM, including overlapping activities, critical activities, floats, and their application for resource management through active exploration in an interactive digital game environment. All students were able to successfully finish the game and accomplish its goal. The recorded data in the debriefing mechanism of the game showed clear evidence indicating that all students realized that some activities are less time sensitive and can be postponed in response to resource allocation problems. In the end, more than half of the students who never had any exposure to CPM and its fundamental concepts were able to correctly list the critical activities. The data collected through the articulation platform indicated that students perceived the proposed gamified pedagogy as interesting, engaging, and effective. The outcomes of the pre- and post-assessments (i.e., a post-game exam compared to a benchmark exam) indicated that the proposed method was able to help all students define and identify critical activities and effectively use floats to address resource allocation problems. This study is part of an ongoing research project. More data will be collected from the students via surveys and semi-structured interviews to analyze their experiences throughout the proposed learning method more rigorously and better understand the strengths and limitations of the proposed pedagogy. These will be the foundations for future studies.

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References

Abrams, E. M. (1994). How the Maya built their world: energetics and ancient architecture. University of Texas Press.

Ausubel, D. P., & Robinson, F. G. (1969). School learning: An introduction to educational psychology. Holt, Rinehart Winston. New York.

Boothby, T. (2018). Empirical Structural Design for Architects, Engineers and Builders. Institute of Civil Engineers (ICE) Publishing. London. United Kingdom.

Bruner, J. S. (1966). Toward a theory of instruction (Vol. 59). Harvard University Press.

Deshpande, A. A., & Huang, S. H. (2011). Simulation games in engineering education: A state-of-the-art review. *Computer applications in engineering education*, *19*(3), 399-410.

Dicheva, D., Dichev, C., Agre, G., & Angelova, G. (2015). Gamification in education: A systematic mapping study. *Journal of Educational Technology & Society*, *18*(3).

Driscoll, M. P. (2000). Psychology of learning for instruction, 2nd ed. Needham Heights, MA: Allyn and Bacon.

Ilbeigi, M., Bairaktarova, D., & Morteza, A. (2023). Gamification in Construction Engineering Education: A Scoping Review. *Journal of Civil Engineering Education*, 149(2), 04022012.

Kuh, G. D., Kinzie, J., Schuh, J. H., & Whitt, E. J. (2011). Student success in college: Creating conditions that matter. John Wiley & Sons.

Maturana, H. R. (2006). Self-consciousness: how? when? where?. *Constructivist Foundations*, 1(3).

Newstetter, W. C., & Svinicki, M. D. (2015). Learning theories for engineering education practice. In *Cambridge handbook of engineering education research* (pp. 29-46). Cambridge University Press.

Pelling, N. (2011). The (short) prehistory of gamification. *Funding Startups (& other impossibilities)*, 9.

Piaget, J. (1952). The origins of intelligence in children. W W Norton & Co. New York.

Sheppard, S., Macatangay, K., Colby, A., Sullivan, W. M., & Shulman, L. S. (2009). *Educating engineers: Designing for the future of the field* (Vol. 9). San Francisco, CA: Jossey-Bass.

Tobias, S. (2010). Generative learning theory, paradigm shifts, and constructivism in educational psychology: A tribute to Merl Wittrock. *Educational Psychologist*, *45*(1), 51-54.

Violatti, C. (2018). Neolithic Period. *Ancient History*. Retrieved from https://www.ancient.eu/Neolithic/

Weimer, M. (2002). Learner-centered teaching: Five key changes to practice. John Wiley & Sons.

Werbach, K., & Hunter, D. (2013). For the Win: How Game Thinking Can Revolutionize Your Business. Wharton Digital Press. Philadelphia, PA.