Leading Construction Technology Systems
for Today's Environmental and Social Crises
Villacís, E., Ayarza, C., Bucheli, J., Miranda, H.,
Flórez-Estrada, M., Yazdani, S., and Singh, A. (eds.)
LATAM-SEC-2024, Quito, March 4-8, 2024

TEACHING LINEAR SCHEDULING THROUGH GAMIFIED ACTIVE EXPLORATION

MOHAMMAD ILBEIGI[1]

[1]Deptment of Civil, Environmental, and Ocean Engineering, Stevens Institute of Technology, Hoboken, USA

Previous research convincingly demonstrates that incorporating active and collaborative instructional methods, along with effective strategies to foster student engagement, consistently yields improved learning outcomes. However, conventional educational programs in construction engineering and management are often inflexible, providing limited opportunities for students to actively participate in experiential learning that could contribute to firsthand experience and guide them in finding solutions. This study addresses this gap by developing and empirically evaluating an innovative gamified pedagogical approach aimed at teaching linear scheduling through guided active exploration within a digital gaming environment. The proposed approach and its associated game are grounded in constructivist learning theory. A scenario-based interactive game named Zebel was created using the Unity game engine. Employing a set of pre- and post-assessment tools, the proposed method was implemented and assessed in a graduate-level course on construction planning and scheduling to gather empirical data. The results indicate that the proposed pedagogy effectively guided students, even those without prior knowledge of linear scheduling, in discovering fundamental concepts and systematic solutions for the presented problems.

Keywords: Experiential Learning, Constructivism, Game, Construction Scheduling

1. INTRODUCTION

Experiential learning in engineering education revolutionizes the traditional classroom approach by emphasizing hands-on, practical experiences that complement theoretical knowledge. Immersing students in real-world engineering challenges gives them invaluable insights into problem-solving, critical thinking, and teamwork (Kuh *et al*. 2011). This immersive approach nurtures creativity, adaptability, and a deeper understanding of engineering principles, equipping students with the skills and confidence needed to excel in their future careers. Emphasizing experiential learning fosters a dynamic, engaging learning environment that bridges the gap between academia and industry, producing well-rounded engineers ready to tackle complex, cutting-edge challenges in today's rapidly evolving world (Weimer 2022).

The rich history of experiential learning in civil and construction engineering highlights the significant opportunities for cognitive development via direct experience and reflection on effective practices in specific situations (Boothby 2018). While modern complexities in the construction industry make real-world trial and error impractical for education, the twenty-first century offers a promising solution. Recent advancements in computer science enable educators to create digital interactive environments where students can explore diverse scenarios and learn from their experiences. These digital tools provide a safe and dynamic space for students to enhance their understanding and skills in construction engineering, fostering a more efficient and effective learning process. In spite of its considerable potential, findings from a systematic review on gamification in construction engineering education (Ilbeigi 2023) indicate a lack of understanding about the design of gamified pedagogies for active exploration, particularly those based on learning theories. To address this essential knowledge gap, the primary goal of this study is to design, develop, and empirically examine a novel gamified pedagogical approach that helps students learn linear scheduling through guided active exploration in an interactive game setting. In the remainder of this article, first, gamification and its fundamental principles are briefly reviewed. Next, the methodology, including the design of the gamified approach based on the constructivism learning theory and development of the game, is introduced. The implementation process and the assessment results to measure the effectiveness of the proposed method are then described. Finally, the primary contributions of this study to the body of knowledge are summarized in the conclusion section.

2. METHODOLOGY

The methodology outlined in this study is centered on two key components: 1) gamification and 2) constructivism learning theory.

2.1 Gamification

Gamification, also referred to as serious games, entails designing and developing interactive games with a purpose beyond amusement (Dicheva et al., 2015). When meticulously crafted, this type of game can establish a dynamic environment, enabling users to actively immerse themselves in new technical concepts, explore diverse scenarios, acquire fresh knowledge, and relate it to their previous knowledge (Deshpande and Huang 2011). A gamified system comprises three primary groups of elements: (1) Dynamics, (2) Mechanics, and (3) Components. Dynamic elements explain the overarching framework of the game. Examples include the narrative of the game which defines the goals users aim to achieve along with any constraints that may affect the ways in which those goals are pursued. Mechanics formulate the process to progress and move forward in the game. Examples include how users may cooperate and compete. Components are specific instantiations of the first two elements within explicit contexts of the game. Examples contain points, badges, and other users' achievements (Werbach and Hunter 2012).

2.2 Constructivism Learning Theory

The constructivist learning theory originated from Piaget's theory of cognitive development (1952) and has been enriched by contributions from various researchers like Bruner (1966) and Ausubel and Robinson (1969), making it the most widespread form of cognitivism (Tobias 2010). According to constructivism, learners actively construct knowledge as they try to comprehend their observations. Unlike knowledge transmission, constructivism prioritizes knowledge construction (Sheppard *et al.*, 2009). Its core principle emphasizes individualized knowledge representation, where learners engage in active exploration and interaction, building upon their own experiences to reconcile inconsistencies between their existing knowledge and new encounters (Tobias 2010).

In the gamification world, the constructivist view of learning has found favor (Driscoll 2000). This project proposes a gamified approach guided by a constructivist framework specifically designed for gamified learning (Newstetter and Svinicki 2015). This learning framework is built upon six essential principles:

- **Modeling:** During this stage, learners' existing knowledge is utilized, and they are furnished with pertinent background information aligning with the game's learning objectives. The modeling phase aims to assist students in forming a conceptual understanding of the processes necessary to attain the game's learning goals.

- **Reflection:** In this step, learners systematically structure their thoughts, establishing connections between their initial ideas while discerning between more crucial and less significant assumptions. The modeling and reflection phases collaborate to empower learners in constructing their personalized synthesis of knowledge, laying the groundwork for the development of strategies.
- **Strategy Formation:** During this phase, learners actively engage in formulating suitable playing strategies to address the challenges posed by the game.
- **Scaffolded Exploration:** In this step, learners navigate the game world, constructed with scaffolding, enabling them to observe the effects and outcomes of their actions through diverse game elements. The objective is to lead learners towards independent problem-solving, with the game providing support as they participate in various activities.
- **Debriefing:** This pivotal step entails a thorough examination of the events that transpired during the game, an analysis of the reasons behind them, and a discussion of the mistakes and corrective actions implemented by the learners. Debriefing serves as a crucial bridge between game experiences and learning, aiding learners in analyzing and relating the activity to their mental models.
- **Articulation:** During this phase, students collaboratively share their game experiences and the knowledge they have acquired, working together towards a collective understanding. Articulation fosters the social negotiation of meaning, a pivotal method for problem-solving, building individual knowledge, establishing identities, and facilitating effective teamwork.

The game has been crafted by incorporating these essentials. In the Modeling process, students entering the game possess a foundational understanding of construction projects. To augment their knowledge, demonstration animations are employed to present background information related to the construction scenarios in the game. Each game chapter kicks off with a brief animation introducing the problem, objectives, tasks, and resources. Moving on to Reflection, students leverage their existing knowledge in conjunction with the game's design and features to comprehend the game's objectives and how to initiate and progress within it. As for Strategy Formation, once students have a solid grasp of the game and its features, they embark on strategizing how to optimize available resources for solving the presented problems. Factors like the type and quantity of equipment needed are considered, all while mindful of constraints such as budget and time. In the Scaffolded Exploration phase, the game ensures that students consistently observe the outcomes of their decisions via game components such as points. Depending on the achieved performance, the game may offer hints to support students' learning journey. Moving to the Debriefing phase, the game asks users to articulate their observations, decision outcomes, and strategies employed to solve problems, contingent on the scenario and students' performance. Students are encouraged to input their responses in a pop-up box. Lastly, the Articulation step leverages an online forum, providing students with a space to connect with peers, share ideas, and discuss findings. The forum serves as an interactive platform where students can pose questions and engage in constructive discussions around each other's comments and ideas.

2.3 Design of the Game

The game comprises multiple chapters, each focusing on different topics in construction scheduling. One particular chapter, the focal point of this paper, aims to guide students in exploring linear scheduling for horizontal construction projects. A linear schedule is a project management tool employed to display a schedule in two dimensions, typically representing time and distance. It finds common applications in projects characterized by linear construction properties or repetitive tasks, such as road construction, bridge building, and railway projects. The standard method to solve a linear scheduling problem relies on velocity diagrams. A velocity diagram is a two-dimensional chart that plots the progress of each activity (in distance) against time.

To expose students to a linear scheduling problem, the game presents a pipeline project scenario with three activities requiring different construction equipment: (1) trenching using an excavator, (2) laying pipes with a mobile crane, and (3) backfilling using a loader. The game's demo provides detailed information, including production rates for each piece of equipment, project duration, and the cost of using each piece of equipment per unit of time. The student's task is to determine the start time for each activity to minimize both the project's duration and cost.

To minimize the project duration, start times should not be too late. To reduce the total cost, the start times for the second and third activities should not be too close to their predecessors to prevent conflicts that would cause one equipment to idle behind another. This way, the game challenges students to strategize and optimize the project's scheduling efficiently.

During gameplay, students initially acquaint themselves with the tasks, constraints, and available resources in the game through a demonstration. Subsequently, they formulate an initial strategy and estimate start times for each activity. By observing the consequences of their strategy through the game’s feedback, they refine their tactic and persist in their attempts until the goal is achieved. To deepen the comprehension of their experiences, students are obliged to explain their approach to solving the problem and analyze the outcomes in the debriefing system. Specifically, when a student successfully attains the goal, a pop-up box prompts them to convey a systematic method to solve this type of problem. Next, the game presents a velocity diagram illustrating the solution without explicit explanation and repeats the question to evaluate if students modify their intended method after examining the diagram.

2.4 Developing the Game

The Zebel game was developed utilizing the Unity platform, which provides an online game development engine. This platform offers a diverse range of services, including software development kits and libraries for a wide range of game plugins and pre-defined functionalities. To support the debriefing and articulation aspects of the game, a cloud-based application was devised using Google Firebase. Upon the completion of each game, log data and along with user information, are stored in a NoSQL database in JSON format for subsequent post-processing purposes. Figure 1 provides a snapshot of the gameplay.

3. IMPLEMENTATION AND DATA COLLECTION

The gamified pedagogical method was implemented in the graduate-level course, CM-529: Construction Planning and Scheduling, at the Department of Civil, Environmental, and Ocean Engineering (CEOE) at Stevens Institute of Technology during the Spring semester of 2023. The Zebel game served as the formal teaching tool, with a total of forty students enrolled in the course for that semester. To ensure ethical compliance and safeguard the personal information of human subjects, the project adhered to Institutional Review Board (IRB) requirements, obtaining proper approval before conducting the study.

The efficacy of the envisioned gamified teaching method is assessed through four evaluation instruments: 1) a prior knowledge survey, 2) a benchmark test, 3) a game assignment, and 4) a post-game test. The prior knowledge survey, conducted in the initial class session, identifies students with prior exposure to standard problem-solving methods related to the target topics. If some students have significant prior knowledge, their data is excluded from the assessment analyses. The benchmark exam, also administered in the first session, evaluates students' ability to solve a linear scheduling problem before learning new materials in the class. In the game assignment, students use the Zebel game. The game log files keep a record of all students' inputs, which are then analyzed to comprehend how students formulate and adjust their strategies throughout the game. Finally, the post-game exam, given a week after the game assignment, aligns with the benchmark exam to gauge students' learning progress after using the proposed game-based approach.

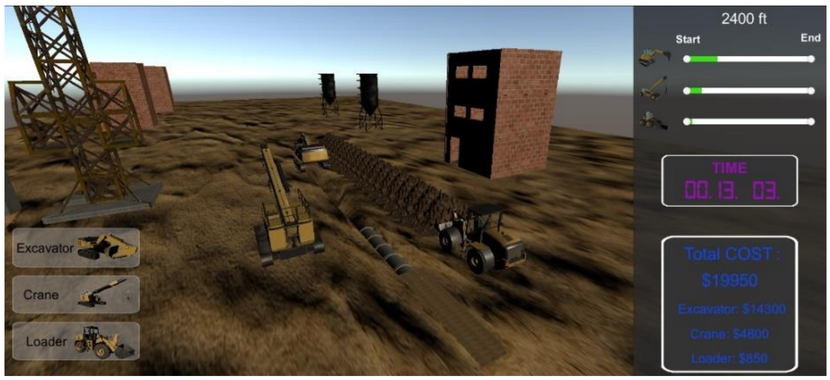

Figure 1. Snapshot of the gameplay

4. RESULTS

The results of the prior knowledge survey revealed that ten out of the 40 students registered in the course had prior experience with linear scheduling from previous courses they had passed. Despite their active participation in class activities, including game assessments, their data were excluded from the analysis for this study. From the benchmark exam, it was found that only five out of 30 students (i.e., 16%) were able to solve the linear scheduling problem, and among them, only four could describe a systematic strategy. However, none of the solutions were as clear as the standard methods utilizing velocity diagrams. During the game assignment, all students successfully completed the game. On average, they took 6.3 attempts, with a minimum of three and a maximum of 15 tries. Analysis of the recorded log files showed that students initially tended to schedule each activity consecutively to shorten the project's total duration. However, as they progressed, they learned that this strategy led to conflicts and idle equipment. Subsequently, they began adding buffers to delay the start times for the second and third activities (i.e., laying pipes and backfilling) to avoid conflicts. After playing the game, 19 out of 30 students (i.e., 63%) provided meaningful strategies aligned with the standard solutions, which increased to 26 students out of 30 (i.e., 87%) after viewing the velocity diagram.

After completing the game assignment, students utilized the articulation platform to exchange ideas about their strategies and discoveries. A total of 26 comments were submitted, with students actively participating in discussions and offering positive feedback. In the post-game exam, conducted following the game assignment, 27 out of 30 students (i.e., 90%) successfully solved the linear scheduling problem, indicating a noteworthy enhancement in their comprehension of the concepts.

5. CONCLUSION

This study introduced an innovative gamified pedagogical method aimed at evaluating its efficacy in improving students' capacity to devise systematic solutions for linear scheduling problems. The design of the proposed method and game was rooted in the constructivism learning theory. Empirical data derived from pre- and post-assessment instruments, along with scrutinized log files, illustrate that the gamified approach effectively familiarized students with fundamental scheduling concepts, particularly for horizontal projects. Feedback from the articulation platform revealed that students perceived the gamified pedagogy as intriguing, engaging, and effective. This research is part of an ongoing project, and additional data will be gathered through surveys and semi-structured interviews to comprehensively analyze students' experiences with the proposed method, gaining a deeper understanding of its strengths and limitations. These insights will serve as a foundation for future studies.

Acknowledgments

This study is based upon work supported by the National Science Foundation under Grants EEC-2106257. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

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

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

Bruner, J. S., *Toward a theory of instruction* . Harvard University Press, Boston, Massachusetts, 1966.

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

Dicheva, D., Dichev, C., Agre, G., and Angelova, G., *Gamification in education: A systematic mapping study*. Journal of Educational Technology & Society, International Forum of Educational Technology and Society, 18(3), 75-88, 2015.

Ilbeigi, M., Bairaktarova, D., & Morteza, A., *Gamification in Construction Engineering Education: A Scoping Review*, Journal of Civil Engineering Education, ASCE, 142(2), 04022012, 2023.

Kuh, G. D., Kinzie, J., Schuh, J. H. and Whitt, E. J. *Student success in college: Creating conditions that matter*, John Wiley & Sons, Hoboken, New Jersey, 2011.

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

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

Sheppard, S., Macatangay, K., Colby, A., Sullivan, W. M., and Shulman, L. S., *Educating engineers: Designing for the future of the field*. Jossey-Bass, San Francisco, California, 2009.

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

Weimer, M. *Learner-centered teaching: Five key changes to practice*, John Wiley & Sons, Hoboken, New Jersey, 2011.

Werbach, K., and Hunter, D., *For the Win: How Game Thinking Can Revolutionize Your Business*. Wharton Digital Press. Philadelphia, Pennsylvania. 2013.