

Work-in-progress: A gamified pedagogical system for teaching construction scheduling through active exploration

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Abstract

This is a work-in-progress paper to share the latest outcomes of an ongoing research project focused on developing and assessing the effectiveness of a novel approach for construction engineering education based on guided active exploration in a digital game environment. The objective of this study is to assess the effectiveness of guided active exploration in a digital game environment on students' ability to discover systematic solutions for fundamental engineering problems contextualized in domain-specific settings. To address this objective, we are designing and developing an online game, called *Zebel: Genesis*. The game coupled with a series of pre- and post-assessment tools will be used as learning materials in a graduate-level construction scheduling course in the Department of Civil, Environmental, and Ocean Engineering (CEOE) at Stevens Institute of Technology to collect empirical evidence for qualitative and quantitative analyses. The design of the game is based on the Constructivism learning theory. The Constructivism learning framework for gamification that forms the foundation of our game platform consists of six essential elements: (1) modeling; (2) reflection; (3) strategy formation; (4) scaffolded exploration; (5) debriefing; and (6) articulation. The final game will have three chapters: (i) linear scheduling, (ii) task dependencies and critical path, and (iii) equipment planning and resource management. So far, we have developed the preliminary version of the first two chapters, and we will use it for a pilot study to examine the functionality of the game and assessment tools. This work-in-progress paper presents the game platform, our assessment strategy, and implementation plans.

Introduction

The history of construction dates back to the Neolithic era (i.e., New Stone Age), roughly from 9000 BC to 5000 BC [1]. 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 335 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 time 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 [2]. 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 calculate 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. While 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 [3-4]. 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 [5]. Of course, the complex nature of the construction industry in the twenty-first century cannot afford 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.

Theoretical Framework

Constructivism learning theory assumes that “knowledge is constructed by learners as they attempt to make sense of their experiences” [6]. In constructivism, learning is a journey of discovering meaningful information from interactions between what learners already know and what they come into contact with [7-8]. The focus of constructivism is on knowledge construction rather than knowledge transmission [9]. 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 [10]. The constructivist view of learning has been embraced by the gamification world [11]. The proposed gamified approach in this project is guided by a constructivism framework developed specifically for learning through gamification [12]. This learning framework is based on the following six essentials:

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.

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.

Strategy Formation: This involves the learners’ efforts to form appropriate playing strategies to solve the problems the game provides.

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.

Debriefing: This involves a description of events that occurred in the game, 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.

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.

Designing of the Game

The Zebel: Genesis is a mobile/tablet game 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. The scenario-based problems facilitate sense-making and engage students in understanding, analyzing, and solving open-ended problems in that field. The game has been designed based on the essentials of the constructivism learning theory. 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 consequences of their actions constantly through game elements such as points and resource utilizations. Depending on the complexity of a problem and the students' performance, the game may provide them some hints as well. Eventually, based on the students' progress, feedback from the game, and new information that is added to the students' 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: Genesis sometimes prompts users to explain their observation, 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.

Developing the Game

The first chapter of the game is already available publicly on a dedicated website [13]. Figures 1 shows two snapshots of the first chapter of the game that simulates a pipeline project consisting of an excavator, a crane, and a loader. The main goal of this scheduling problem is to finish the project as soon as possible with minimal cost of renting equipment. The standard approach to solve this problem is to use a velocity diagram. In a typical scheduling class, students directly learn about the problem and the velocity diagram as the standard solution without any chance to discover the solution through active exploration. However, in the proposed method, students, without any background knowledge related to the standard solution, will try to solve this problem empirically through active exploration in the game's digital environment. 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 piece of equipment, 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. After recording the response, the game will show a velocity diagram created based on the user's decisions in the game without any explicit explanation about the diagram and repeat the question to check whether the user changes his/her proposed strategy after seeing the velocity diagram (Figure 2).

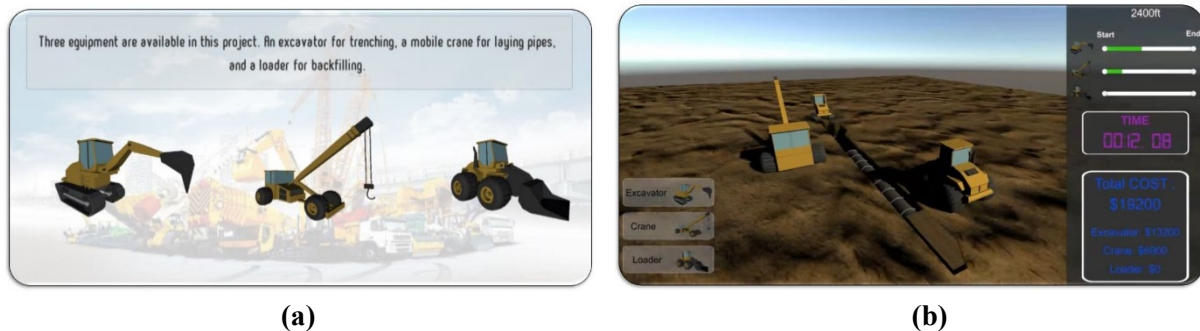


Figure 1: (a) Snapshot of game demo explaining the project equipment (b) Snapshot of the gameplay



Figure 2: Snapshots of (a) debriefing tool asking about the user's strategy; (b) presenting velocity diagram

Assessment Instruments

A series of pre- and post-assessment analyses will be conducted to examine the effectiveness of the proposed method on students' ability to discover systematic solutions for fundamental engineering problems contextualized in construction scheduling and planning settings. First, a *prior knowledge survey* will be administered in the first session of the class to identify students who have had exposure to standard ways to solve these problems. If some students have considerable prior knowledge in the target topics of this research project, their data will be excluded from the assessment analyses. Second, a *benchmark exam* will be conducted in the first session of the class to understand the extent to which students are able to comprehend and solve construction planning and scheduling problems without specific lessons in the three target areas corresponding to each chapter of the game. Third, one week before the sessions in which a topic related to the three target areas is discussed in the class, students will work on *game assignments* in which they need to play the game, report their observations, understanding, and strategies that they used to achieve the goals defined in the game. Fourth, at the beginning of each session that focuses on the target topics, students will take a *post-game test* that evaluates their ability to solve related fundamental problems after playing the game during the game assignment that they have done before the session. Fifth, at the end of each session after the lecture is delivered and students are introduced to the concepts and standard ways to solve the problems, they will take a *post-lecture test* that aims to assess their understanding after the delivery of the standard lecture. Sixth, at the end of the course, a *structured survey* will be conducted to collect students' perceptions of the extent to which various aspects of the course, including the game, were helpful for developing their understanding of the engineering core concepts. Seven, based on the outcomes of the survey, a group of students will be invited for *semi-structured interviews* to understand the effectiveness of the proposed method on their learning process more rigorously.

The assessment instruments except the game assignments and post-game tests will be used in another class as a control group that does not use the game as a learning tool. In addition to the data collected through the pre- and post-assessment tools, we will analyze the data collected using the game (i.e., user log files, debriefing tools, and articulation platform) quantitatively and qualitatively to further assess the effectiveness of the proposed pedagogical strategy.

Conclusion

In this work-in-progress paper, we aimed to share the latest outcomes of an ongoing research project focused on developing and assessing the effectiveness of a novel approach for construction engineering education based on guided active exploration in a digital game environment. More specifically, we briefly introduced the learning theory that formed the foundation of the proposed pedagogical approach, the game and its design and development plan, and the assessment strategies instruments. We have scheduled a pilot study for Summer 2022 and full implementation and data collection during the Fall 2022 and Spring 2023 semesters.

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