International Journal of Engineering Education Vol. 33, No. 2(B), pp. 831–846, 2017
Printed in Great Britain
0949-149X/91 $3.00+0.00

Developing Problem-Solving Skills in Construction Education with the Virtual Construction Simulator*

FADI CASTRONOVO[1], PEGGY N. VAN METER[2], SARAH E. ZAPPE[3], ROBERT M. LEICHT[4] and JOHN I. MESSNER[4]
[1] Construction Management Program, Department of Engineering, California State University East Bay, Hayward, CA 94544. E-mail: fadi.castronovo@csueastbay.edu
[2] Educational Psychology Program, Department of Educational Psychology Counseling and Special Education, The Pennsylvania State University, University Park, PA16802. E-mail: pnv1@psu.edu
[3] College of Engineering, The Leonhard Center for the Enhancement of Engineering Education, The Pennsylvania State University, University Park, PA16802. E-mail: szappe@engr.psu.edu
[4] Computer Integrated Construction (CIC) Research Program, Department of Architectural Engineering, The Pennsylvania State University, University Park, PA16802. E-mail: rml167@psu.edu, jim101@psu.edu

The ability to solve complex problems is an essential skill that a construction project manager must possess when entering the architecture, engineering, and construction industry. Such ability requires a mixture of problem-solving skills, composed of lower and higher-order thinking skills, which include the ability to develop and evaluate construction plans and manage the execution of such plans. However, introducing students to such complex problems can be a challenge in a typical construction educational program. To support this challenge, the traditional methodology of delivering design, engineering, and construction instruction has been going through a technological revolution, due to the rise of computer-based technology. For example, in engineering classrooms, and other disciplines, educational simulation games are used to support the development of problem-solving skills. This paper presents evidence to support the contention that educational simulation games can help the learning and retention of transferable problem-solving skills, which are crucial to solve complex construction problems. A sample group of 34 architectural engineering students, from a 4th year construction class, participated in a quasi-experiment where they had to play the three modules of the Virtual Construction Simulator 4 (VCS4). A crossover repeated measures quasi-experimental design assessed the gains in problem solving skills that construction students gained from playing the VCS4. The participants completed all three learning modules of the VCS4, and they were assessed before and after each treatment. Based on a series of analyses of the results, the researchers were able to conclude that the students gained and transferred problem-solving skills from playing all of the VCS4 modules. This study provides evidence that the implementation of educational simulation games can support the gain of problem-solving skills necessary to solve complex construction problems.

Keywords: construction education; engineering education; simulation games; serious games; problem-solving

1. Introduction

One of the critical objectives of engineering education is to foster students' knowledge, skills, and attitudes obtained, through education, experience, and achievement [1]. According to the Accreditation Board for Engineering and Technology (ABET) a student should be prepared to identify, formulate, and solve engineering problems [2]. These objective holds true especially for construction engineering students, who are challenged with complex real-world problems during their education and after graduation. The ability to solve complex problems is an essential skill that a construction manager or engineer must possess when entering the Architectural, Engineering, and Construction (AEC) Industry. Such ability requires a mixture of skills. These skills include the ability to develop and evaluate construction plans and manage their effective execution.

Traditional construction educational methods challenge students with partial problems, which do not fully represent the complexity of the construction process. When teaching the process of planning and managing of a construction site, instructors typically lecture and assign to the students the responsibility of developing a schedule of the construction process based on a set of drawings. In some cases, the students are given the chance to discuss in class the factors that influence productivity on site, such as weather, improper sequencing and resourcing, learning curve and fatigue of the workers. However, this method usually covers the dynamic and ever-changing nature of a construction site on a surface level, and it typically does not provide the students with real-time feedback as they develop the construction plan. Therefore, students gain only surface knowledge on the process of scheduling and managing a construction project. This surface knowledge does not entirely meet the learning objective mentioned earlier, which requires the learning of a range of problem-solving skills.

* Accepted 13 December 2016.

The process of teaching scheduling is based on the traditional method of generating schedules in the industry, where one reviews architectural drawings, compiles a general list of construction activities, visualizes the sequencing logic, and translates the logic to the schedule. However, the process of generating schedules is not only inefficient but it also creates high cognitive load requirements on the scheduler's working memory [3]. To address such challenges researchers and industry members have begun to visualize the construction process with the use of Building Information Modeling (BIM) and 4D scheduling software. This software allows the user to tie schedule data to 3D graphical representations of the elements to be built. By visualizing the schedule of construction, users can enhance their cognition by interacting with appropriate representation methods, giving them the chance to develop sensible schedules. The benefit of developing and visualizing schedules has led to the adoption of such software in the classroom [4].

One instruction method to improve construction planning education is to include educational simulation games in the classroom. Educational simulation games provide students with experiential learning environments, which have illustrated a great potential in enhacing the learning process. In particular, educational simulation games research has shown how they can support the learning process to solve complex, ill-structured problems. Also, educational simulation games increase students' motivation, as they challenge them and promote curiosity. In addition to being engaging and fun, educational simulation games can challenge students to solve ill-structured problems. In particular, the construction industry and pedagogy have leveraged educational simulation games to enhance the problem-solving process. One example is the Virtual Construction Simulator (VCS) educational simulation game.

The VCS challenges students to develop and manage a plan for the construction for a variety of structures. In the game students phase and sequence building elements and select construction methods. Students then execute the construction plan within a specific time and budget, while the game challenges them with field factors, such as weather and workforce learning. Previous research with the third iteration of the VCS simulation game, VCS3, has shown strong potential for motivating and engaging students [5]. The initial assessment results demonstrated the VCS3's ability to motivate the students and to meet the learning objectives [6]. These learning objectives aimed at assessing the student's lower-order thinking skills, such as the identification of the field factors and assessing their general knowledge of construction planning processes.

However, the planning and managing of construction schedules require the utilization of both lower and higher-order thinking, such as identifying factors and explaining how decisions affect the plan. Therefore, additional research was needed to illustrate the educational game's ability to support the development of problem-solving skills, composed on both lower and higher-order thinking skills. With this paper, the researchers address the challenge of assessing problem-solving skills, by designing a new version of the game, VCS4, with new learning modules along, and with the development and implementation of an assessment framework.

2. Background

2.1 Construction scheduling

One essential skill-set of a construction manager or engineer is the ability to develop a plan of construction [7]. According to Mubarak [8], one of the major parts of a construction plan is the schedule of construction. Therefore, one of the main tasks that a construction manager or engineer has to perform is to develop project schedules. In the planning process, construction managers use project schedules to illustrate and communicate the planned construction process to the rest of the project team and other project stakeholders [3]. This schedule includes all of the construction activities, based on the provided drawings, necessary for the complete construction of a facility [9]. Traditionally, the development of construction schedules is conducted by reviewing architectural drawings, compiling a general list of construction activities, visualizing the sequencing logic, and translating the logic on paper or within a critical path method (CPM) scheduling software. When developing a plan or schedule of construction, a manager must strike a balance between quality, time, safety, and cost [10]. These factors are interrelated, since affecting one of them will have a direct effect on the others. For example, shortening the time of construction would typically drive the cost higher and cause a lowering of the project's quality [10]. Therefore, the development of a construction schedule requires the ability to: quickly review activities and their relationships; perform rapid schedule modifications; and analyze if their results are features that industry professionals have identified as highly valuable [3]. However, according to Karshenas and Sharma [3], this process can reduce planning efficiency by causing a cognitive overload of the scheduler's memory.

Cognitive load is a theory of instructional design that highlights the limited capacity of learners' working memory [11, 12]. Working memory is the component of a learners' cognitive system that is used for processing new information, making connections, and developing and carrying out plans. The capacity of working memory is limited, however. Learners have only a limited amount of cognitive resources that can be dedicated toward these activities at any one point in time. Cognitive load theory encourages instructional designers to analyze the demands that a task places on learners limited cognitive resources. A central tenet of this theory is that these cognitive demands are highest for beginning learners who do not yet have well-organized stores of knowledge that can be used to support and guide thinking. To address challenges of cognitive overload, caused by the process of developing and interpreting schedules, researchers and developers, such as Karshenas and Sharma [3], have begun to visualize the construction process.

2.1.1 Visualization, BIM, and 4D scheduling

According to Card et al. [13] and Mazza [14], visualization is cognition that can be enhanced through the interaction with appropriate representations, for example with computer-generated visual data [15]. Kuljis et al. [16] note that visualization is also a decisive step for decision making, understanding and problem-solving. In construction, providing the possibility to represent the process through computer-generated visual data has been recognized as an efficient way to eliminate redundancy and optimize planning [16–18]. The introduction of Building Information Modeling (BIM) and 4D scheduling software in the construction industry has started to change the scheduling process. BIM software such as Autodesk Navisworks, Synchro, and Vico leverage visualization principles to allow the user to link scheduling information, coming from CPM schedule applications such as Primavera Scheduling and Microsoft Project, to 3D models. Therefore, with the implementation of 4D modeling (3D plus time as the fourth dimension), the industry has begun to address the challenges of the construction process. Visualization is being implemented for the capabilities offered by 4D modeling and simulations. The simulation process allows project teams to visualize the construction process, identify conflicts, and consider safety concerns along with other issues [19]. Even though one of the major uses of 4D scheduling applications is to support the review of construction schedules through an animated sequence of construction activities, additional uses include tasks such as: trade and space coordination; assembly sequences; development of different scenarios for interference analysis; and dynamic 3D visualization of discrete-event operations simulations [9, 20]. Therefore, the visualization of the asplanned process in 4D environments has revolutionized how project teams schedule, by allowing them to understand spatial constraints and explore design and construction alternatives before construction starts [21]. In addition to industry, construction educational programs have adopted visualization software in their classrooms to address some of the challenges they have encountered in teaching the planning and managing of construction sites.

2.1.2 Challenges in construction education

Anderson [22] believes that problem-solving is an essential process in learning, especially in science and mathematics [23]. According to Schunk [23], problem-solving is one of the most important cognitive processes that occur during learning [24]. Problem-solving can be defined as a cognitive process necessary to achieve a goal, which could have a direct solution [18, 23]. According to Pólya [26], there are four main phases in the problem-solving process: *understanding the problem, devising a plan, carrying out the plan,* and *looking back*. Similarly, Bransford and Stein [27] developed the IDEAL model for problem-solving. This process is iterative in nature and non-linear. These models provide the basic problem-solving cognitive subprocesses that Mayer and Wittrock [25] summarize as *representing, planning,* and *executing*. Van Meter et al. [28] proposed the Integrated Problem-Solving (IPS) model which aimed at encompassing problem-solving processes, prior knowledge, and symbol system transformation (e.g., transformations between verbal and visual representations of the problem or problem components). The IPS model has shown its ability to illustrate effectively the student's analysis processes in solving free body diagrams in statics [21, 22]. Such models must be considered when addressing problem-solving educational research.

The construction planning and execution process is constantly confronted with unexpected factors and unknowns, making it an ill-defined problem. According to Schraw et al. [30], an ill-defined problem has multiple or no solution, and there is no single, correct procedure that leads to an answer. Ill-defined problems can be contrasted with well-defined problems. Well-structured problems are ones in which the problem solving goal and the constraints for achieving the goal are clear; these problems can often be solved through the application of linear problem solving steps. Although construction planning and execution is clearly an ill-structured problem, most traditional construction classrooms present students with construction problems that have been fragmented and reduced to well-defined problems. Unfortunately, such instructional methods could be enhanced to help students develop the decision-making skills that are required for the construction industry [24, 25]. Therefore, traditional teaching approaches remain limited in providing students with the necessary experience to prepare them for the professional world [33]. To tackle challenges in teaching how to solve ill-structured problems, Jonassen [34] suggests that instructors must provide constructivist and situated cognition approaches to learning.

2.2 Game-based learning

Constructivist theorists believe that instructors must develop environments where students learn by actively engaging with the environment through the use of different types of material [23]. Based on constructivism epistemology [35, 36] several theories have been developed such as experiential learning [37, 38], situated learning [39, 40], constructionism learning [41, 42]. Such theories are essential to understand the process with which an individual learns and how an instructor must engage such learner. Hence, to address the challenges presented in the previous section, researchers have started to develop multimedia tools to support the processes of solving complex or ill-structured problems. Educational research has placed particular focus on multimedia learning to provide experiential learning environments to students [4, 43]. Mayer's cognitive theory of multimedia learning defines learning as the process of building mental representations and constructing knowledge from words and pictures [43]. Multimedia learning provides students with an environment where they experience and interact with a variety of media. One example is educational simulations games, which have become subjects of research in education. Simulation games allow the student to learn by interacting with a repeatable and unique environment [44]. Educational simulation games target multiple levels of the learning process and have shown great promise in their ability to provide students with an experiential learning environment. Also, educational simulation games are being analyzed for their ability to support learning by providing a close to realistic environment for problem-solving through visualization, exploration, and immediate feedback [45, 46]. Because of their ability to present complex or ill-structured problems, promote curiosity, and provide immediate feedback, simulation games have demonstrated an increase in the learners' motivation [47, 48].

2.2.1 Simulations and simulation games in construction

The advances in visualization and educational gaming research have illustrated the value of simulations and simulation games in planning and managing construction [49]. For example, VITASCOPE and STROBOSCOPE, which are 3D visualization systems that animate results from discrete event simulations of construction processes, have demonstrated the benefits of simulations in the evaluation process of excavation operations [50]. Educational simulations, such as MERIT [51], and educational simulation games, such as COINS [52], have also been implemented in academic environments to enhance the learning of project management. Rojas and Mukherjee [53] developed Virtual Coach, a Web-based situational simulation environment that presented the participants with fast decision-making events. Another example is the Project Management Simulation Engine, which allows a user to develop educational simulations for project management [54]. Lastly, Nikolic [6] and Lee et al. [5] developed the Virtual Construction Simulator 3 (VCS3), an educational simulation game, to improve the learning process of planning and managing of a construction project.

The VCS3 was evaluated for its ability to support students' learning, motivation, and engagement, which were measured through questions that focused on content knowledge and conceptual understanding [55]. The assessment focused on students' ability to list, identify, and rank factors that affect the schedule (e.g., "List factors that affect construction activity duration"). The initial assessment results demonstrated the VCS3's ability to motivate the students and increase their general knowledge of construction planning processes [6]. However, the results still do not fully reveal the VCS3 simulator's ability to promote a range of problem-solving skills, from lower to higher-order thinking skills. The inherent challenge lies in developing an adequate assessment instrument for such skills. The models developed by Van Meter et al. [28] and Jonassen [34] could provide the framework for assessing the range of skills necessary to solve complex problems. Therefore, the next phase of the VCS(4) development aimed to further address this challenge of assessing problem-solving skills, by revisiting the game design and adopting an additional assessment framework.

2.3 Research questions

The brief background has illustrated the advances in the fields of visualization, engineering education, and simulation games. In particular, the role of the VCS3 was highlighted for its ability to support the engagement and motivation of students, together with the assessment of surface knowledge. From this brief review, areas of potential research have been identified; in particular, the necessity to further evaluate the value of construction simulation games in acquiring problem-solving skills, ranging from lower to higher-order thinking skills. Therefore, the goal of this study was to evaluate the game's ability in supporting the learning and development of problem-solving skills in the field of construction management and engineering. Additionally, the researchers were interested in evaluating the implementation procedure of the VCS4 game, to support future instructors in maximizing educational gains when applying the game in a classroom environment. To tackle the set research goals, the researchers developed a new version of the game, the VCS4, and adopted a new assessment framework.

The research questions explored in this study are:

1. Does playing the VCS simulation game lead construction students to gain problem solving skills?
2. Do gained problem solving skills transfer from one simulation module to the next?
3. Do construction students benefit from playing all three simulation modules?
4. Does the order in which the simulation modules are completed affect student gains in construction problem solving skills?

With the first question the researchers were interested in understanding if learners yielded an education gain from planning and managing the construction simulation of a wooden pavilion, the erection of a steel superstructure of a dormitory, and the placement of a cast-in-place structure of the same dormitory.

As suggested by Mayer [56], the second question examines the level of carry-over, or near transfer, of problem solving skills necessary to solve complex construction problems. We expect that students will not only gain in these skills by completing each VCS module but also that students will maintain these gains from one module to the next. The ability to acquire transferable skills is key to tackle future scheduling problems and managing construction sites. Therefore, it is of great interest to the researchers to evaluate the transferability of the skills gained from playing the modules, and to understand how many modules to be implemented for enhancing such retention. This question is examined by comparing pretest scores across the three modules. If there is a carry-over effect, significant gains in pretest scores should be demonstrated from the first to the third pretest. A parallel comparison of posttest scores was also completed and a significant difference.

The third question aimed at understanding if the students have to play all of the modules in order to yield the highest educational gains. This question addresses the potential of the wooden module in being an instructional scaffold, as defined by Wood et al. [57], for the steel and concrete modules.

The fourth question aims at understanding if the order of implementation of the three learning modules of the VCS4 affected students' learning outcomes. The answers to these questions provide supporting evidence to the theory that educational simulation games can help the learning and retention of transferable problem-solving skills, which are necessary to solve complex construction problems.

3. Virtual construction simulator 4

The instructional package employed in this study is the Virtual Construction Simulator 4 (VCS4). The game is part of an ongoing research effort to engage students in an active learning environment by simulating the planning and managing of a construction project. The VCS4 was developed to further evaluate the benefits of problem-solving skills, together with an assessment instrument, which is addressed in the methodology section.

The VCS4 challenges the students to develop and manage a plan for the construction of three structures. In the game, students phase and sequence building elements and select construction methods. Students then execute the construction plan within a specific time and budget, while the game challenges them with field factors, such as weather. With the VCS4 the researchers target construction students in their early and advanced years of study. To target this audience, new steel and concrete learning modules were added to the VCS. The first module engages the students in the construction of a wooden pavilion. The wood module's difficulty level was designed to target high school and early undergraduate students. The steel and concrete modules are of the same facility, a large college dormitory addition. The steel and concrete module's difficulty level was designed for students that possess higher levels of knowledge in construction engineering, for example undergraduate students in their last years of studies and graduate students taking advanced courses in construction engineering. Because of the complex nature of the planning and managing cast-in-place concrete structures, the concrete module offers the students' a higher challenge than the steel module. The research focus on problem-solving required adding an iterative nature to the game. Therefore, the game mechanics had to allow the students to go through several iterations or plays of problem-solving. The iterative nature of playing allows the students to test their mental model and develop better problem-solving skills. With this iterative nature at its core, the research team developed a new game mechanic (see Fig. 1).

3.1 A problem-solving model for the VCS4

The design and development of the VCS4 leveraged

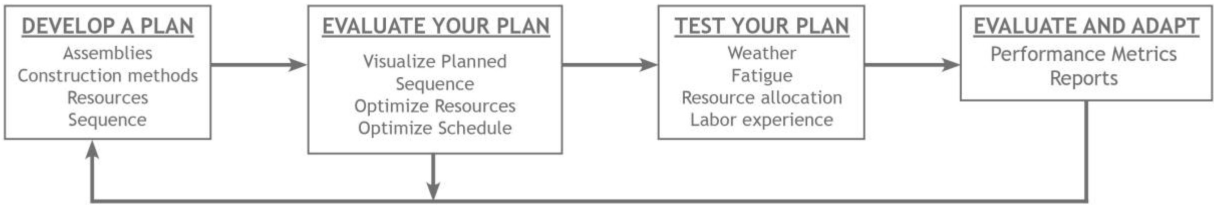

Fig. 1. VCS4 game mechanics (modified from [24]).

research in cognitive models and theories, instructional design guidelines for multimedia learning, fundamentals of human-computer interaction theories, and 4D simulation guidelines [15, 24]. Based on previous research a model for solving construction engineering problems was developed, see Fig. 2, which was described in previous publications [24].

This model is based on the Van Meter et al. IPS [28] model with a focus on ill-structured problems provided by Sinnott [58] and Jonassen [59] models, together with Winne and Perry's model of self-regulated learning and metacognition [60]. Retaining the structure of the IPS model, the proposed model is divided into three main phases: *problem representation, problem execution,* and *solution evaluation*. For each of these phases, cognitive operations, metacognitive regulative processes, visual representations, and prior knowledge are identified. The cognitive operations were inspired by Jonassen's [59] model for ill-structured problems. Leveraging the Winne and Perry model, each phase was divided into three metacognitive sub-phases: *define goals, monitor,* and *evaluate* [60]. Supporting *visual representations,* and necessary and acquired *prior knowledge,* are outlined for each of the phases. In this proposed model the game's graphical user interfaces are utilized as the visualization systems. An example of the model's detailed processes can be found in Table 1.

3.2 VCS4 graphical-user interface

The graphical user interface (GUI) was redeveloped for the VCS4. The design was based on the problem-solving model developed by the researchers, discussed in the previous section, specific for the solving of complex construction problems [24]. With the VCS4 the research focused on implementing full interaction with the 3D model. An exploration and walkthrough scene were developed to include an interactive 3D model. This allowed the students to directly click on any building element and view construction information regarding the element [24]. The grouping scene allows the students to directly click on the desired 3D elements and generate a construction assembly. The sequencing scene asks the students to directly select the 3D construction assemblies and select a construction relationship, such as overlapping or sequential. The schedule of construction is then generated for the student, and it can be previewed through a viewable 4D simulation. The simulation scene gives the chance to execute their plan and receive feedback

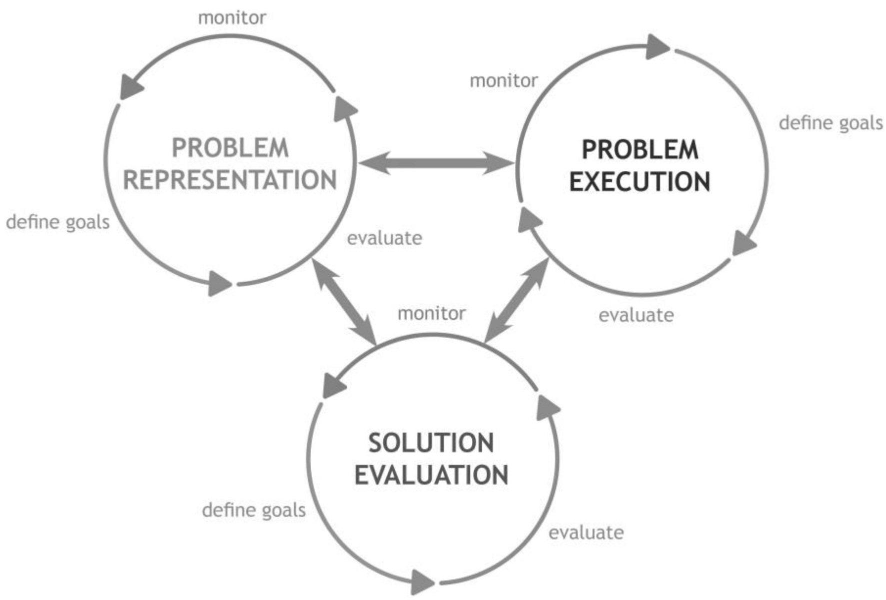

Fig. 2. Problem-Solving Model for Construction Engineering Education (modified from [24]).

Table 1. Problem-Solving Model Example

Problem Representation			
Cognitive Operations Definition	**Metacognitive Regulative Processes Definition**	**Visual Representation**	**Prior Knowledge**
Prior Knowledge activation related to problem task	Evaluate prior knowledge related to the problem task	Project Description	Prior Knowledge of related tasks
Read problem statement	Define problem tasks and goals		
Identify problem tasks	Monitor understanding of the problem statement		
Analyze problem tasks	Evaluate understanding of the problem statement		
Prior Knowledge activation related to building model	Evaluate prior knowledge related to the building model	Building Model	Prior Knowledge of similar facility
Explore building model	Define goals for the exploration of the building model		
Identify building model components	Monitor understanding of building model		
Analyze building model	Evaluate understanding of building model		

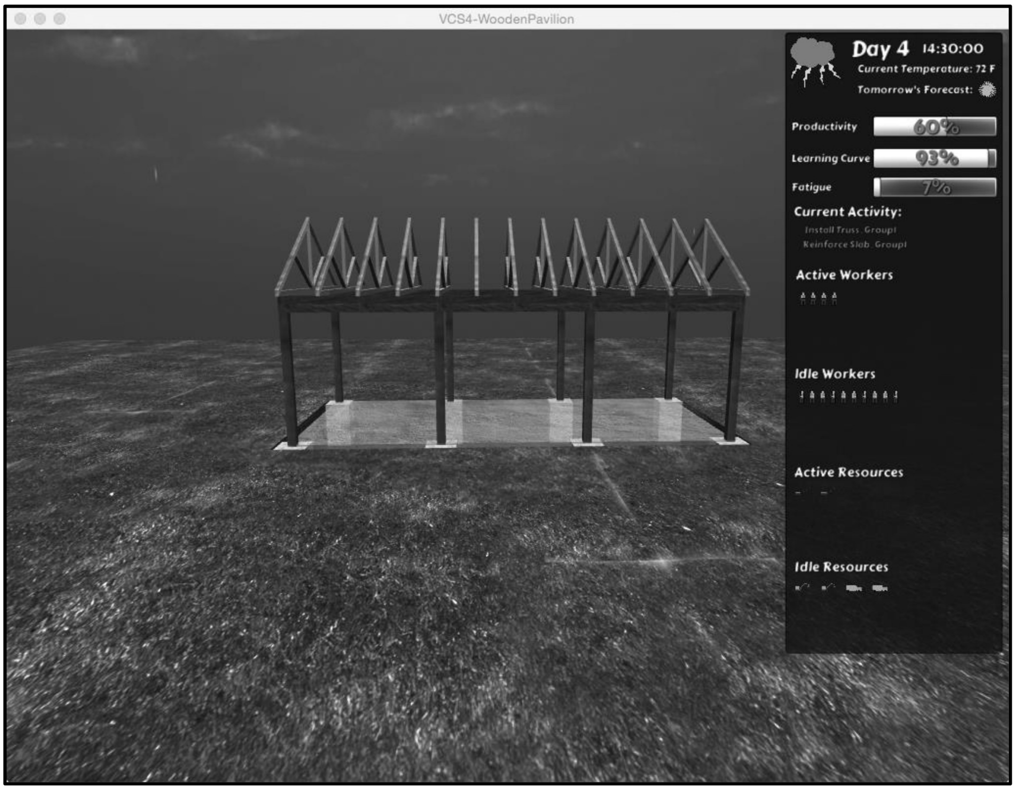

Fig. 3. Screenshot of the VCS4—Simulation Scene.

on the construction process. The workers' performance, such as learning curve, activity, and safety can be monitored with graphical bars (see Fig. 3). Lastly, the daily reports give feedback on the overall performance of the construction process. The VCS4's features required a flexible game engine with robust 3D physics and user interaction capability. To satisfy these requirements the Unity™ game engine was chosen. The Unity™ game engine allowed the research team to incorporate photorealistic graphics, streamline the 3D content generation and enable flexible publishing of the game [61]. The game was coded in the C# programming language.

4. Methods

4.1 Participants

Participants were 34 architectural engineering students, attending a fourth-year construction course at a university in the United States. The students were given the option of engaging in the study as part of their participation grade. All participants gave consent for their data to be used.

4.2 Assessment

4.2.1 Assessing learning in simulation games

While simulation games have been a subject of research in the past and praised for their benefits, they are still to be broadly accepted in academic environments. According to Feinstein and Cannon [62], these slow advances are caused by the challenges in developing experimental studies and appropriate methodology to assess the learning benefits of these games. These challenges include the time constraints for developing a valid assessment instrument and the use of non-indicative metrics for learning, (e.g., game performance, the level of success, or achieving a correct solution) [63]. This paper intends to address these challenges by assessing learning outcomes for students who use the VCS. In particular, we follow Mayer's [56] recommendation that assessments of retention and transfer are appropriate methods for determining learning outcomes from student engagement with multimedia.

The design of our assessment instrument of retention and transfer was guided by Brookhart's [64] suggestion, that one must first identify the thinking skills necessary to solve problems. Additionally, Burns et al. [65] suggest that the first step in assessing thinking skills is the identification and development of learning objectives. Similarly, when assessing learning in simulation games, Cannon and Burns [66] make the development of learning objectives, based on Bloom's Taxonomy [67], an essential step in their evaluation framework. This step allows an instructor or evaluator to select the performance required to meet the learning objectives. Feinstein [68] used this development framework to draft an assessment instrument for a food service simulation game. The instrument contained a set of questions for each of Bloom's six cognitive learning levels [24]. From his experimental results, Feinstein [68] illustrated the role of simulation games in supporting the learning of the necessary cognitive skills in food servicing. Feinstein's work, with Cannon and Burn's framework, illustrated a path that future educational game developers can leverage.

4.2.2 Instrument

An assessment instrument was developed to evaluate a broad range of problem solving skills necessary to plan and manage the construction of different types of building systems (e.g., wood, steel, and concrete). The instrument was developed based on the problem-solving model describe in Section 3.1 and in previous publications [24]. The model aimed at introducing to students a range of problem-solving skills, ranging from lower to higher order thinking skills. To evaluate gains in knowledge and assess the students' problem-solving skills, the test was developed with the same 5 open-ended questions for each of the VCS modules, with an evaluation rubric specific for each module. The construction methods selection question (number 2) was the only one of the 5 questions that differed for each of the modules. Each of the questions were mapped to a specific learning objective, thinking skill level, and desired problem-solving skill. An example of the test can be found in Table 2. The instrument has been reviewed by both construction and educational psychology faculty. Students' answers were scored according to a rubric. This rubric shows the problem-solving domain and the learning objectives that a question is tied to. The question item was evaluated on six levels: significantly impressed, slightly impressed, performed adequately, found area lacking, infeasible answer, and no answer provided. The level of performance is tied to a scalable point system, for a total maximum score of 70 points, scaled to a 100 percentage score. The higher-order thinking skills were weighted to be worth double the points than the lower-order thinking skills.

4.3 Design and procedure

A crossover repeated measures quasi-experimental design assessed the gains in problem solving skills that construction students gained from playing the VCS4. All participants completed all three learning modules of the VCS4, but in two different orders, (see Fig. 4). Half of the students were randomly assigned to complete the modules in the order of wood, concrete, steel (Group 1). The other half of the students completed the modules in the order of wood, steel, concrete (Group 2). All participants completed the easier wood module first so that they could learn how to play the simulation game while working with less complex content. The variation in order between the steel and concrete modules tests the possibility that student learning is affected by whether the first module tackled after this introduction is the most difficult, concrete module or the steel module, which is at a middle level of difficulty.

Participants completed all three modules over a three-week period with one week between each one. Participants completed the pre-test for each module. The pre and post tests were through an online course management tool. Pre-tests were completed the day before playing the game module. Post-tests were completed the day after the module. The quasi-experiment was designed to have one dependent variable and three independent

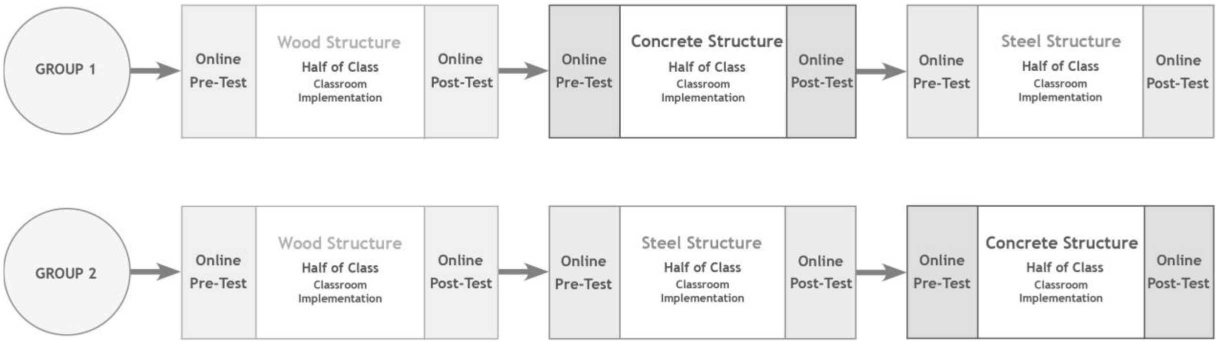

Fig. 4. Experimental Procedure.

Table 2. Assessment Instrument for the Wood Module

Problem-Solving Phase	Problem-Solving Skill	Learning Objective	Thinking Skill	Question
Problem Representation	Evaluating a developed construction plan.	Evaluation of the developed plan based on time, cost, sequence, weather, resourcing, equipment, labor efficiency of construction, and future field variations.	Lower Order	1(a). Which factors would you consider in the development process of the construction sequence? Please list at least 3 factors.
			Higher Order	1(b). Explain for at least 2 of them the reason for considering them.
		Selection of optimal construction methods based on their cost, productivity, and resource required.	Higher Order	2. You are asked to evaluate the construction methods for the placement of concrete of the footings of the structure. Which method would you select? Walking Cart or Direct Chute? Please thoroughly explain your choice.
Problem Execution	Monitoring of solution execution during construction.	Tracking the productivity of the construction by looking at: checking hired resources, checking weather, tracking learning curve, and fatigue.	Lower Order	3(a). Construction has begun, and as a superintendent, you are tracking the construction process on a daily basis. Please list at least 3 actions would you perform each day to maximize productivity.
			Higher Order	3(b). Explain for at least 2 of them the reason for performing them.
Solution Evaluation	Evaluation of built solution.	Evaluation of factors that have influenced the construction process: weather, lack of resources, improper sequencing.	Lower Order	4(a). Construction is running behind schedule and you are asked for a progress report. You arrive on site and you see that the construction has stopped or slowed down. Please list at least 3 possible causes.
			Higher Order	4(b). Explain for at least 2 of them how they can affect productivity.
		Plan a new sequence for a similar structure and list factors that might affect the construction: overlapping activities, construction methods, cost reduction, resource allocation.	Lower Order	5(a). You are asked to plan and manage the construction of a similar wooden structure. Please list 3 factors that you will be looking for when planning and managing your next project.
			Higher Order	5(b). Explain your choices for at least 2 of them.

variables. The dependent variable was based on the percentage scores from the assessment instrument. The first independent variable was order. This between-subjects variable captures the two different orders in which the modules were completed. The second independent variable is treatment. This within-subjects variable captures the time sequence of module completion (i.e., first, second, third) regardless of order. The final independent variable is the within-subjects pre-test/post-test variable.

5. Results and analysis

The four research questions of this study were explored through a series of analyses that directly tested the comparisons of interest. The first research question, which asked if the VCS modules lead to improvements in students' problem solving skills, was tested by three paired samples t-tests that compared pre- and post-test scores for each of the modules. The second research question considered

Table 3. Descriptive Statistics

Treatment	Group Assignment	Module Test	Mean	Std. Deviation	N
Treatment 1	Group 1	Wood Pre-test	47.9829	9.40974	17
	Group 2	Wood Pre-test	50.2529	8.55867	17
	Total		49.1179	8.93157	34
	Group 1	Wood Post-test	72.1847	13.87030	17
	Group 2	Wood Post-test	75.2935	11.24518	17
	Total		73.7391	12.53308	34
Treatment 2	Group 1	Concrete Pre-test	59.7476	9.97608	17
	Group 2	Steel Pre-test	63.6988	8.31753	17
	Total		61.7232	9.26374	34
	Group 1	Concrete Post-test	69.0759	14.20374	17
	Group 2	Steel Post-test	70.1676	17.23844	17
	Total		69.6218	15.56286	34
Treatment 3	Group 1	Steel Pre-test	61.7647	12.26309	17
	Group 2	Concrete Pre-test	59.6635	17.73797	17
	Total		60.7141	15.05327	34
	Group 1	Steel Post-test	75.2100	16.01099	17
	Group 2	Concrete Post-test	73.5294	15.61725	17
	Total		74.3697	15.59722	34

if students benefitted from completing all three modules. Two paired samples t-tests were performed, with post-test scores at the three treatment time points serving as the dependent variable, tested this question. The third research question asked if the benefits from one module treatment carried over to the next module. This question was examined by a performing two paired samples t-tests, with pre-test scores at the three treatment time points serving as the dependent variable. The final research question concerned the potential effects of module order. This hypothesis was tested as a main effect of order in a mixed model ANOVA where order was the between-subjects variable. This mixed model ANOVA also tested for any potential interactions between the variables of interest.

The data was analyzed with the SPSS Statistics software package. Participants were 9 females 25 males. The average age for the full sample was 22.75 years, with a $\mu_{age\_group1} = 22.05$, and a $\mu_{age\_group2} = 23.53$. The average grade point average for the full sample was 3.22, with a $\mu_{GPA\_group1} = 3.23$, and a $\mu_{GPA\_group2} = 3.21$. Table 3 shows means and standard deviations of pre-test and post-test scores for all three modules and both order conditions. Inter-rater agreement on the application of the scoring rubric was established with the pre-test and post-test from the first module. Two raters scored the first module's responses for one subject's pre-test and post-test. Cohen's κ showed good inter-rater agreement, $\kappa_{pre\text{-}test} = 0.78$ $p < 0.05$, and $\kappa_{post\text{-}test} = 0.804$, $p < 0.05$. Disagreement was resolved through discussion. All remaining tests were scored by the first author of this paper. The data met the assumptions of normality, sphericity, and homogeneity of covariances. Of the three pre-test and three post-test scores, only the pre-test for the concrete module failed to meet the homogeneity of variance assumption. ANOVA is robust with respect to these violations when participants are equally distributed across conditions. There were no outliers in the data set.

5.1 *Analysis for educational gains*

Three paired samples t-tests tested for differences in pre-test and post-test scores for each of the three modules. A Bonferonni adjustment was applied to the $\alpha = 0.05/3$ to control for a Type I error. This analysis collapsed all participants into a single group and tested for differences at each of the three treatments. The estimated marginal means for each pre- and post-test are shown on Fig. 5. These differences were significant for all three treatment times, $t_{wood}(33) = 13.74$, $p = 0.000 < 0.02$, $d = 2.36$, $t_{concrete}(33) = 4.65$, $p = 0.000 < 0.02$, $d = 0.8$, and $t_{steel}(33) = 4.43$, $p = 0.000 < 0.02$, $d = 0.76$. These analyses demonstrate that the VCS improves students' problem solving skills. Regardless of the content of the module, students' problem solving skills increased from before to after completing each simulation game.

5.2 *Analysis for transfer of gains*

The analysis for the near-transfer of the educational gains between the modules was conducted by performing two paired samples t-tests on the pre-tests for the treatments. The analysis collapsed all participants into a single group and tested for differences in the pre-test scores for the first and second treatment, and for the second and third treatment (Treatment 1: wood; Treatment 2: concrete/steel; and Treatment 3: steel/concrete). A Bonferonni

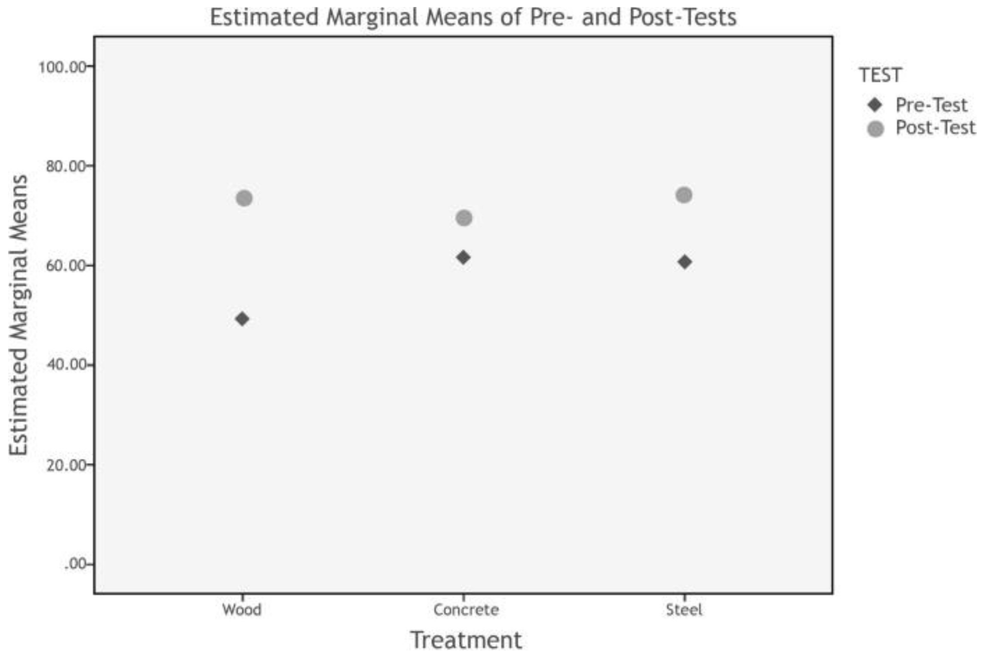

Fig. 5. Treatment's Pre- and Post-Tests Estimated Marginal Means.

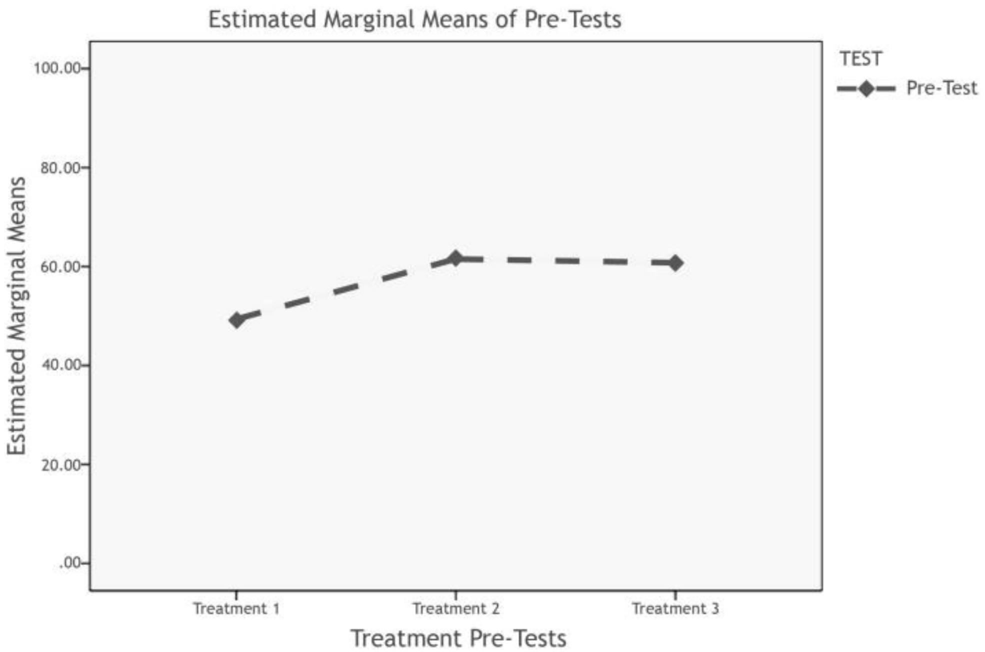

Fig. 6. Treatment's Pre-Tests Estimated Marginal Means.

adjustment was applied to the $\alpha = 0.05/2$ to control for a Type I error. The estimated marginal means for each pre-test are shown on Fig. 6. The differences were significant for only the first and second treatment, $t_{treatments1\text{-}2}(33) = 8.38, p = 0.000 < 0.025, d = 2.9, t_{treatments2\text{-}3}(33) = 0.45, p = 0.655 > 0.025, d = 0.16$. Based on the non-significant difference of the pre-test scores of the second and third treatment, there is evidence to support the hypothesis that the students were able to transfer their skills. Therefore, the educational gains in problem solving skills gained after the first treatment were transferred to the following treatment.

5.3 Analysis for instructional scaffolding benefits

The second research question asked if participants benefitted from completing all three modules or if the benefits tapered off after only one or two modules. This question was explored by performing two paired samples t-tests. The analysis collapsed all

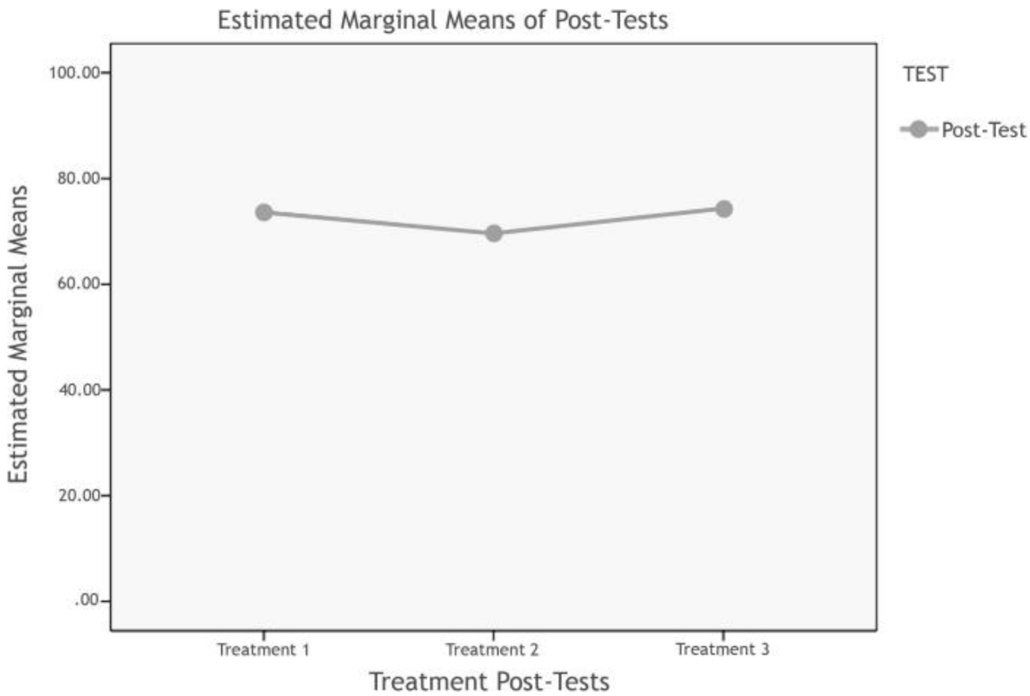

Fig. 7. Treatment's Post-Tests Estimated Marginal Means.

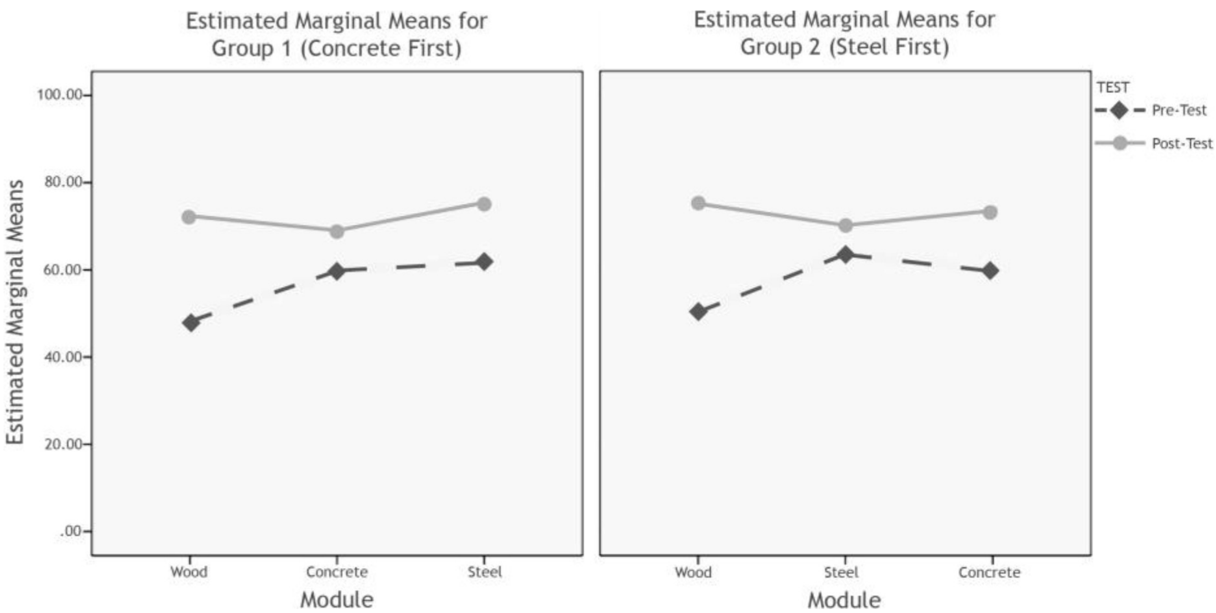

Fig. 8. Test and Treatment Interaction Estimated Marginal Means for each Group.

participants into a single group and tested for differences in the post-test scores for the first and second treatment, and for the second and third treatment (Treatment 1: wood; Treatment 2: concrete/steel; and Treatment 3: steel/concrete). A Bonferonni adjustment was applied to the α = 0.05/2 to control for a Type I error. The estimated marginal means for each post-test are shown on Fig. 7. The differences were significant for only the second and third treatment, $t_{treatments1\text{-}2}(33) = 1.75$, $p = 0.09 > 0.025$, $d = 0.6$, $t_{treatments2\text{-}3}(33) = 2.55$, $p = 0.016 < 0.025$, $d = 0.8$. Based on the significant difference of the post-test scores of the second and third treatment, there is evidence to support the hypothesis that the students needed the second treatment as a scaffold for the third treatment.

5.4 Analysis for implementation order

A mixed model ANOVA 2 (order: group 1, group 2) $\times$ 2 (pre-test/post-test) $\times$ 3 (treatment) tested for differences between the two order conditions. This analysis also tested for any interactions between the variables in this study. The estimated marginal means for each test, treatment, and group are shown on Fig. 8. The interaction between the tests, treatments, and groups was not statistically significant, $F(2,64) = 0.202$, $p = 0.81 > 0.05$, partial $\eta^2 = 0.01$. There was no statistically significant between-subject effect of the two groups, $F(2,64) = 0.096$, $p = 0.76 > 0.05$, partial $\eta^2 = 0.003$. Based on the non-significant interaction of the with-in subject's effects, together with non-significant interaction of the between-subject effects, there is no evidence to support the hypothesis that there is a difference in the order with which the modules are administered. Therefore, whether the students were introduced to the steel or concrete modules, after the wooden module, did not yield a significant difference in their educational gains.

6. Discussion of results

The presented study aimed at evaluating the pedagogical value of the Virtual Construction Simulator 4. In particular, the goal of this study was to evaluate the game's ability in supporting the learning and development of problem-solving skills in the field of construction management and engineering. Additionally, the researchers were interested in evaluating the implementation procedure of the VCS4 game, to support future instructors in maximizing educational gains when applying the game in a classroom environment. The following is a discussion of the research questions, which addressed the goal of assessing the pedagogical value and implementation process of the VCS4.

For the first question, based on the data analysis there is significant evidence to support the statement that the students were able to improve their problem-solving skills and meet the learning objective for each of the game's module. The findings are further supported the high-value of *Cohen's d* for each of test. A substantial difference in educational gains was achieved when playing the wooden module. While the differences between the pre and post-test of the concrete and steel are not comparable to the wooden modules, they are still significant within each module. Therefore, each of the VCS4's module can be utilized to improve future learners' ability to solve complex construction problems. By providing such evidence, the author can conclude that the game can be used as valid learning tool in a classroom. This outcome supports the current literature and research that theorizes that educational games are valid learning tools [69]. Additionally, these findings illustrate how educational games can support students in learning complex problem-solving skills. In particular, these findings illustrate that students can gain and improve their skills when dealing with complex construction simulations. These skills are essential for students, as they will have to apply them when entering the AEC industry.

Based on the analysis for the second research question, there is evidence to support the hypothesis that the students were able to transfer their skills. The findings are further supported the high-value of *Cohen's d* for each of test. The estimated marginal mean of the third treatment was lower than the second treatment. However, this drop was not significant. Hence, the researcher can conclude that the gained skills were retained by the students and transferred from the second treatment onto the third. Therefore, the educational gains in problem solving skills gained after the first treatment transferred to the following treatments. This finding is key in understanding if the skills gained from playing the VCS4 game do not dissipate over time, making the implementation of the game an impactful intervention. Future research should evaluate the ability of learners to perform far-transfer of the skills gained from playing with the VCS4, or other simulation games.

Based on the analysis for the third question, there is evidence to support the hypothesis that the students needed the second treatment as a scaffold for the third treatment. The findings are further supported the high-value of *Cohen's d* for each of test. Therefore, the students benefitted from playing all of the VCS' module. While there was no significant difference between the first and second post-test, the post-test score for the second treatment was lower than the first. This phenomenon could explained by Kapur and Bielaczyc's [70] theory of Productive Failure. This theory was expanded from Schwartz and Bransford [71] research on *preparation for future learning*. Kapur and Bielaczvc believe that instructors should introduce students with ill-structured problems to prepare them in solving other problems, even if they fail at solving the ill-structured problems. Therefore, it is possible that the students in this study required the second treatment as a productive failure to perform significantly higher in the third treatment. To conclude, future research should further investigate the role of educational games as scaffolds to support productive failure.

For the fourth question, there is no evidence to support the hypothesis that there is a difference in the order with which the modules are administered. Therefore, whether the students were introduced to the steel or concrete modules, after the wooden module, did not yield a significant difference in their educational gains. This finding supports future instructors in understanding how to implement multiple modules and achieve the highest educational gains.

7. Conclusions

Construction education is evolving due to the rise of visualization and BIM software in the industry. Visualization software provides academics with the necessary tools to introduce students to experiential learning environments, which enhance the learning process. Such environments are critical as they introduce students to complex problems and allow them to connect verbal knowledge with visual representations. Together with visualization software, educational games are being adopted in the classrooms, as they not only provide students with complex problems, but they also spark students' motivation and engagement. In construction education, previous research with the Virtual Construction Simulator 3 has shown the potential of sparking students' motivation, engagement, and ability to identify factors influencing construction.

With this study the researchers wanted to dive deeper into the pedagogical value of the Virtual Construction Simulator. The team developed a new version of the game, the VCS4, and an instructional assessment framework to evaluate the game's ability to support the learning of problem-solving skills, necessary to solve complex construction problems. By designing a problem-solving model, the researchers were able support the design of the game and of the assessment framework. The new version of the Virtual Construction Simulator, the VCS4, was designed to enhance the learning process by leveraging previous research in the field of construction, visualization, human-computer interaction, educational psychology, and game based learning. The development experience of the graphical user interfaces illustrates how visual representations can be design to support the gain of desired skills. Meanwhile, the assessment instrument was designed to assess problem-solving, composed of both lower and higher-order thinking skills, based on a proposed problem-solving model. The research team has provided an experience that illustrates how an assessment instrument can be aligned to not only to a problem-solving cognition model, but also to visual representations present in the game.

Based on the results, the researchers were able to provide evidence supporting the hypothesis that the chosen sample of construction students were able to gain and transfer problem-solving skills necessary to solve complex construction simulation problems, by playing all of the modules, no matter what order with which they were played. This conclusion provides evidence that construction educational simulation games can be used not only to engage and motivate students, but also to support users in gaining and transferring a range problem-solving skills. This is achieved not only by showing that the game's modules can be used as instructional scaffolds, but also by giving direction to future instructors on how they can implement the game. Also, by illustrating how educational simulation games can support a range of problem-solving skills, further validates how such games should be implemented in learning environments. While the chosen methodology allows the researchers to avoid most internal and external validity threats, there are limitations to the study. For example, the small sample size and the validity of the assessment instruments are potential limitations, which allow the researchers to perform future analysis and experimentation. Future research should look into expanding the sample size to further represent the population of construction students. Additionally, the assessment instrument can be further reviewed by researchers, in order to strengthen its validity. In conclusion, the presented results provide evidence supporting the theory that educational simulation games can help the learning and retention of transferable problem-solving skills, which are necessary to solve complex construction problems.

Acknowledgements—We thank the National Science Foundation (Grant #1226204) for support of the VCS4 game project. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation. We also wish to thank all of the student participants, along with the researchers who have worked on the development of previous versions of the Virtual Construction Simulator.

References

1. American Society of Civil Engineers. *Civil engineering body of knowledge for the 21st century preparing the civil engineer for the future*. Reston, Virginia: ASCE, 2008.
2. ABET, Inc. *Accreditation policy and procedure manual*. Baltimore, MD: Accreditation Board for Engineering and Technology, 1 November 2010.
3. S. Karshenas and A. Sharma, Visually scheduling construction projects. In: *Construction Research Congress 2010*. American Society of Civil Engineers, pp. 490–499.
4. L. P. Rieber, Multimedia learning in games, simulations, and microworlds, *The Cambridge handbook of multimedia learning* 2005, pp. 549–567.
5. S. Lee, D. Nikolic, J. Messner and C. Anumba, The development of the Virtual Construction Simulator 3: An interactive simulation environment for construction management education. In: *Proceedings of the 2011 ASCE International Workshop on Computing in Civil Engineering*, Miami, FL: ASCE, 2011, pp. 454–461.
6. D. Nikolic, *Evaluating a simulation game in construction engineering education: the virtual construction simulator 3*, Pennsylvania State University, 2011.
7. A. Baldwin and D. Bordoli, *Handbook for Construction Planning and Scheduling*, 1 edition. Wiley, 2014.
8. S. A. Mubarak, *Construction Project Scheduling and Control*, 3 edition. Wiley, 2015.
9. K. Chau, M. Anson and J. Zhang, Four-Dimensional Visualization of Construction Scheduling and Site Utiliza-

tion, *Journal of Construction Engineering and Management*, 2004, pp. 598–606.
10. J. Newitt, *Construction Scheduling: Principles and Practices*, 2 edition, Upper Saddle River, N.J: Prentice Hall, 2008.
11. P. A. Kirschner, Cognitive load theory: implications of cognitive load theory on the design of learning, *Learning and Instruction*, 2002, **12**, pp. 1–10.
12. F. Kirschner, F. Paas and P. A. Kirschner, A Cognitive Load Approach to Collaborative Learning: United Brains for Complex Tasks, *Educational Psychology Review*, 2009, pp. 31–42.
13. S. K. Card, J. D. Mackinlay and B. Shneiderman, *Readings in information visualization: using vision to think*, San Francisco, Calif.: Morgan Kaufmann Publishers, 1999.
14. R. Mazza, *Introduction to Information Visualization*, Guildford, Surrey: Springer London, 2008.
15. F. Castronovo, S. Lee, D. Nikolic and J. Messner, Visualization in 4D Construction Management Software: A Review of Standards and Guidelines. In: *Computing in Civil and Building Engineering (2014)*. American Society of Civil Engineers, pp. 315–322.
16. J. Kuljis, R. J. Paul and C. Chen, Visualization and simulation: Two sides of the same coin? *Simulation*, 2001, pp. 141–152.
17. M. Golparvar-Fard, F. Peña-Mora and C. Arboleda, Visualization of Construction Progress Monitoring with 4D Simulation Model Overlaid on Time-Lapsed Photographs, *Journal of Computing in Civil Engineering*, 2009, pp. 391–404.
18. M. E. Haque, *n-D Virtual Environment in Construction Education*, The 2nd International Conference on Virtual Learning, ICVL 2007.
19. B. Koo and M. Fischer, Feasibility Study of 4D CAD in Commercial Construction, *Journal of Construction Engineering and Management*, 2000, pp. 251–260.
20. V. R. Kamat and J. C. Martinez, Visualizing simulated construction operations in 3D, *Journal of Computing in Civil Engineering, ASCE*, 2001, pp. 329–337.
21. K. Song, S. Pollalis and F. Pena-Mora, Project Dashboard: Concurrent Visual Representation Method of Project Metrics on 3D Building Models. In: *Computing in Civil Engineering (2005)*, American Society of Civil Engineers, pp. 1–12.
22. J. R. Anderson, Problem solving and learning, *American Psychologist*, 1993, p. 35.
23. D. H. Schunk, *Learning Theories: An Educational Perspective*, 6 edition, Boston: Pearson, 2011.
24. F. Castronovo, S. E. Zappe, R. M. Leicht and J. Messner, Design of a Construction Simulation Educational Game Through a Cognitive Lens. Seattle, Washington, 2015.
25. R. E. Mayer and M. C. Wittrock, *Handbook of Educational Psychology*, Routledge, 1996.
26. G. Pólya, *How to solve it: a new aspect of mathematical method*, Princeton University Press, 1945.
27. J. D. Bransford and B. S. Stein, *The ideal problem solver. A guide for improving thinking, learning, and creativity.* A Series of Books in Psychology, New York: Freeman, 1984.
28. P. Van Meter, T. A. Litzinger, M. Wright and J. Kulikowich, A Cognitive Study of Modeling During Problem Solving: An integrated problem solving model. In: *Proceedings of the ASEE Annual Conference*. Chicago, IL, USA, 2006.
29. T. Litzinger, P. V. Meter, C. Firetto, L. Passmore, C. Masters, S. Turns and S. Zappe, Improving Students Ability to Model During Problem-Solving in Statics. *2009 ASEE Annual Conference, Austin, TX,* June 14–17, p 15.
30. G. Schraw, M. E. Dunkle and L. D. Bendixen, Cognitive processes in well-defined and ill-defined problem solving, *Appl. Cognit. Psychol.*, **9**, 1995, pp. 523–538.
31. L. R. Lattuca, P. T. Terenzini, J. F. Volkwein and G. Peterson, The changing face of engineering education. *The Bridge: Reforming Engineering Education*, **36**, 2006.
32. A. Mukherjee, E. M. Rojas and W. D. Winn, *Interactive Situational Simulations in Construction Management*, 2005.
33. D. Nikolic, S. Lee, J. I. Messner and C. Anumba, The Virtual Construction Simulator—evaluating an educational simulation application for teaching construction management concepts. In: *Proceedings of the 27th International Conference on Applications of IT in the AEC Industry*, Cairo, Egypt, 2010.
34. D. H. Jonassen, Toward a design theory of problem solving, *ETR&D*, **48**, 2000, pp. 63–85.
35. J. Piaget, *Piaget's theory*, Wiley, New York, NY, 1970.
36. L. S. Vygotsky, *Thought and language*, MIT press December 2014).
37. D. A. Kolb, *Experiential Learning: Experience as the Source of Learning and Development*, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1984.
38. N. M. Dixon, D. Adams and R. Cullins, Learning style. *What works: Assessment, development and measurement* 1997, pp. 37–64.
39. J. Lave and E. Wenger, *Situated learning: Legitimate peripheral participation*, Cambridge, UK: Press Syndicate of the University of Cambridge, 1991.
40. P. Vincini, The nature of situated learning, *Innovations in Learning*, 2003, pp. 1–4.
41. S. Papert and I. Harel, Situating constructionism, *Constructionism*, 1991, **36**, pp. 1–11.
42. M. Cakir, Constructivist Approaches to Learning in Science and Their Implications for Science Pedagogy: A Literature Review, *International Journal of Environmental and Science Education*, 2008, **3**, pp. 193–206.
43. R. E. Mayer, *The Cambridge Handbook of Multimedia Learning*, Cambridge University Press, 2005.
44. C. Aldrich, *Simulations and the Future of Learning: An Innovative (and Perhaps Revolutionary) Approach to e-Learning*, Jossey-Bass Inc., Publishers, 2003.
45. K. Squire, Changing the game: What happens when video games enter the classroom? *Innovate*, 2005.
46. J. P. Gee, *What video games have to teach us about learning and literacy*, New York: Palgrave Macmillan, 2007.
47. T. W. Malone, Toward a theory of intrinsically motivating instruction, *Cognitive Science*, 1981, **4**, pp. 333–369.
48. S-H. Wang, M-C. Lin and C-W. Liao, A Virtual Experiential Learning and Students' Ill-Structured Problem-Solving Ability, *Interact Comput*, 2014, iwu010.
49. J. C. Martinez and P. G. Ioannou, General-purpose systems for effective construction simulation, *Journal of Construction Engineering and Management*, **125**.
50. V. R. Kamat and J. C. Martinez, General-purpose 3D animation with VITASCOPE.
51. MERIT, http://meritgame.com/ (accessed 23 July 2014).
52. T. Korman, Enhancing Civil and Construction Engineering Education through the use of a Web-based Collaborative Simulation.
53. E. M. Rojas and A. Mukherjee, General-Purpose Situational Simulation Environment for Construction Education, *Journal of Construction Engineering and Management*, 2005, **131**, pp. 319–329.
54. A. Martin, A simulation engine for custom project management education, *International Journal of Project Management*, 2000, **18**, pp. 201–213.
55. M. Boekaerts, The On-line motivation questionnaire: A self-report instrument to assess students' context sensitivity. In: Pintrich PR, Maehr ML (eds) *New directions in measures and methods*, Emerald Group Publishing, pp. 77–120.
56. R. E. Mayer, Applying the science of learning: evidence-based principles for the design of multimedia instruction, *American Psychologist*, 2008, **63**, p. 760.
57. D. Wood, J. S. Bruner and G. Ross, The Role of Tutoring in Problem Solving, *Journal of Child Psychology and Psychiatry*, 1976, **17**, pp. 89–100.
58. J. D. Sinnott, A model for solution of ill-structured problems: Implications for everyday and abstract problem solving, *Everyday problem solving: Theory and applications*, 1989, pp. 72–99.
59. D. H. Jonassen, Instructional Design Models for Well-Structured and Ill-Structured Problem-Solving Learning Outcomes. *Educational Technology, Research and Development*, **45**, 1997, pp. 65–94.
60. P. H. Winne and N. E. Perry, Measuring self-regulated learning. In: Boekaerts M, Pintrich PR, Zeidner M (eds) *Handbook of self-regulation*, San Diego, CA, US: Academic Press, 2000, pp. 531–566.

61. Unity—Game engine, tools and multiplatform. http://unity3d.com/unity (accessed 22 March 2014).
62. A. H. Feinstein and H. M. Cannon, Constructs of Simulation Evaluation, *Simulation Gaming*, 2002, **33**, pp. 425–440.
63. J. Gosen and J. Washbush, A Review of Scholarship on Assessing Experiential Learning Effectiveness, *Simulation Gaming*, **35**, 2004, pp. 270–293.
64. S. M. Brookhart, *How to Assess Higher-order Thinking Skills in Your Classroom*, ASCD, 2010.
65. A. C. Burns, J. W. Gentry and J. Wolfe, A cornucopia of considerations in evaluating the effectiveness of experiential pedagogies, In: Gentry JW (ed) *A guide to business gaming and experiential learning*, East Brunswick, NJ/London: Nichols/GP., 1990, pp. 253–278.
66. H. M. Cannon and A. C. Burns, A Framework for Assessing the Competencies Reflected in Simulation Performance, *Developments in Business Simulation & Experiential Exercises*, 1999, **26**, pp. 40–44.
67. B. S. Bloom, *Taxonomy of educational objectives: the classification of educational goals Handbook I, Handbook I,* New York; New York; London: McKay; Longman, 1956.
68. A. H. Feinstein, An Assessment of the Effectiveness of Simulation as an Instructional System in Foodservice, *Journal of Hospitality & Tourism Research*, 2001, **25**, pp. 421–443.
69. K. Squire, *Video Games and Learning: Teaching and Participatory Culture in the Digital Age*, Teachers College Press, Teachers College, Columbia University, 2011.
70. M. Kapur and K. Bielaczyc, Designing for Productive Failure, *Journal of the Learning Sciences*, 2012, 21, pp. 45–83.
71. D. L. Schwartz and J. D. Bransford, A Time for Telling, *Cognition and Instruction*, 1998, **16**, pp. 475–5223.

Fadi Castronovo is an Assistant Professor of Engineering at the Engineering Department of the California State University East Bay. His research interests lie in the areas of engineering education, sustainability, visualization, simulation and educational games, and virtual reality. He has led the design and development of the Virtual Construction Simulator 4, an educational simulation funded by the National Science Foundation. He has instructed and co-instructed several courses in building engineering and virtual facility prototyping.

Peggy Van Meter is currently an Associate Professor of Educational Psychology at Penn State where she has been on the faculty since 1996. Her research includes studies of the strategic and meta-cognitive processes that learners use to integrate multiple representations and acquire knowledge that will transfer and be useful in problem solving.

Sarah Zappe, PhD, is Research Associate and Director of Assessment and Instructional Support in the Leonhard Center for the Enhancement of Engineering Education at Penn State. She holds a doctoral degree in educational psychology emphasizing applied measurement and testing. In her position, Sarah is responsible for developing instructional support programs for faculty, providing evaluation support for educational proposals and projects, and working with faculty to publish educational research. Her research interests primarily involve creativity, innovation, and entrepreneurship education.

Robert M. Leicht is an Associate Professor of Architectural Engineering at the Pennsylvania State University. He is the Director of the Partnership for Achieving Construction Excellence (PACE) at Penn State. Rob is an investigator in the new delivery methods study seeking to empirically capture the impact of integration on project success. Rob leads the construction engineering course dedicated to mechanical and electrical systems construction, he is the lead faculty for the construction option capstone course; he teaches graduate level courses in production management and project delivery systems.

John Messner is a Professor of Architectural Engineering and the Director of the Computer Integrated Construction Research Program at Penn State. He teaches courses in construction engineering and management; Building Information Modeling; and virtual prototyping. He specializes in the use of advanced visualization technologies to improve project design and construction education through the use of virtual facility prototypes (VFP). In addition to his construction visualization research and education initiatives, Dr. Messner is also continuing to expand research efforts in the areas of construction globalization and strategic management in construction procurement methods.