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Effectiveness of a Virtual Project-Based Simulation Game in Construction Education

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ABSTRACT

This research was conducted to evaluate the effectiveness of a virtual project-based simulation game in construction education. For this purpose, Skyscraper Simulator, which is a project-based simulation game focused on the construction management process in an interactive environment, was tested by 135 undergraduate construction students. After finishing the game, students completed a questionnaire to rate the game's effectiveness. Then, quantitative methods were used to investigate their answers. Students also rated their pre- and post- playing construction knowledge, ability and skills in six broad areas typical for their construction management curricula. To measure their perceived learning gains, the self- assessment data on each six area were analyzed by means of a paired-samples T test. The results provide the evidence for positive effect of a virtual project-based simulation game on educating undergraduate construction students, and so for its potential to be used as a supplementary tool in construction education at undergraduate level.

Keywords: Construction, Education, Project-based, Self- assessment, Simulation, Virtual

I. INTRODUCTION

For a long time, games and simulations have been a part of education and learning strategies (Ruben 1999). Recently, game-based learning has come to the forefront of potential pedagogical methods for educating students and providing them with opportunities to practice skills (Bodnar et al. 2016). Several features of games (Dickey 2005, Prensky 2003, Arena and Schwartz 2014, Gee 2003, Shute 2011, Squire 2008, Gee 2005, Shaffer 2006), presented in Fig.1, allow them to be used as learning tools (Dabbagh et al. 2016). Beyond the learning affordances, games have a positive effect on conceptual understanding, problem solving, and critical thinking (Dabbagh et al. 2016). Educational games make learners active in the construction of their own knowledge and awaken them to skills for problem solving. Educational games turn the learning process into a motivating, attractive and engaging experience (POSSA 2011). Research has shown that in undergraduate engineering classrooms, both student learning and attitudes were improved by game-based activities (Bodnar et al. 2016). For example, using an online game during a lecture on Structural Concrete at Master's level is both efficient and enjoyable for students (Ebner and Holzinger 2007). Compared with traditional learning methods, playing a serious game for learning sustainable building design principles and practices leads to significantly higher procedural knowledge gains (Dib and Adamo-Villani 2013).

On the other hand, the use of simulations for education has considerably increased during recent years, and the evidence for their effectiveness is growing (Kincaid et al. 2001). Fig. 2 presents why simulations are important to the field of education (Kincaid et al. 2003). Simulations allow learners to visualize situations and see the results of manipulating variables in dynamic environments that replicate situations which might encounter on the job (Hale Feinstein, Mann, and Corsun 2002), thus increasing their awareness of real world issues and comprehension of course subjects (Philpot et al. 2005, Crown 2001, Hirose, Sugiura, and Shimomoto 2004). Virtual reality display systems can improve the education of construction engineering students. Students can understand construction projects and plans much better when advanced visualization tools are used. Students can very quickly gain experience by developing and critiquing construction schedules in a full-scale virtual environment (Messner et al. 2003).

Construction engineering students are usually treated as passive recipients with linear and fragmented teaching presentations that provide no opportunity for learning the holistic nature of their discipline (Ndekugri and Lansley 1992). Practice of the operational and management skills before stepping into the professional world is fundamental to the success of future construction engineers, which is usually achieved through internships in construction projects, where any small mistake could result in serious technical, financial, or safety results (Sherif and Mekkawi 2009). However, simulations can expose students to realistic experiences without real costs or risks (Nikolić 2011) in order to apply their various skills, and see the results of decisions taken during different stages. A lot of research projects, some of which are presented in Table.1, were conducted to investigate the capabilities of simulation in construction education.

Simulation games can be used as an active learning tool to develop generic professional practice skills of construction students (Agapiou 2006, Scott, Mawdesley, and Al-Jibouri 2004). For example, some simulations developed for teaching construction processes include bidding, planning, schedule review, productivity analysis, resource allocation, risk analysis, and site planning (Nikolic, Jaruhar, and Messner 2011). The Virtual Construction Simulator (VCS) enables students to simultaneously create and review construction schedules, encourages collaborative group work, engage students, and foster greater solution generation through better visualization of construction processes (Nikolic, Jaruhar, and Messner 2011, Lee, Nikolic, and Messner 2014). It forms a more holistic view of construction scheduling and increases interest and motivation in learning about construction processes, cost and time trade-offs, and inherent management challenges. The VCS allows students to explore different strategies of construction process optimization and to observe these processes in real time. It shifts the student's role from passive to active learner (Nikolic et al. 2010). By means of the VCS, students can experience the dynamic nature of building construction projects and observe the differences between as planned and as built schedules and how to manage changes to achieve project goals (Lee et al. 2011).

On the other hand, a variety of research studies have proven the effectiveness of the project-based methods as an alternative pedagogical model in academic environments (Baş 2011). The simulation and project-based education model are useful for construction education (Goedert, Rokooeisadabad, and Pawloski 2012) They are effective alternatives along with the traditional lecture-based method and can be a part of construction curricula (Rokooei and Goedert 2015). Contextually rich project-based interactive simulations show much promise for construction education (Goedert et al. 2013). For instance, Virtual Interactive Construction Education Bridge improves construction knowledge as a result of intervention (Rokooei, Goedert, and Weerakoon 2014).

In order to better prepare construction graduates for entering the workforce, the most efficient possible manner should be recognized and exploited in construction education. So as to achieve this goal, the potential of new pedagogical models should be assessed. Having this aim in mind, the research was conducted to evaluate the effectiveness of Skyscraper, which is a virtual project-based simulation game, in construction education when the target audience is construction students with little or no practical experience.

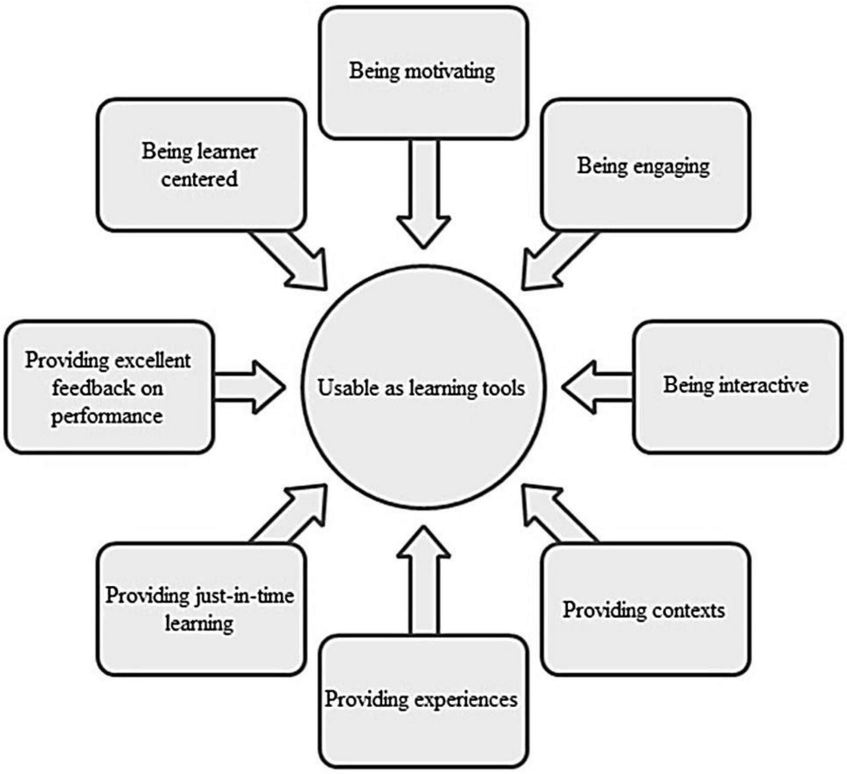

Figure 1: Simulation features as learning tools

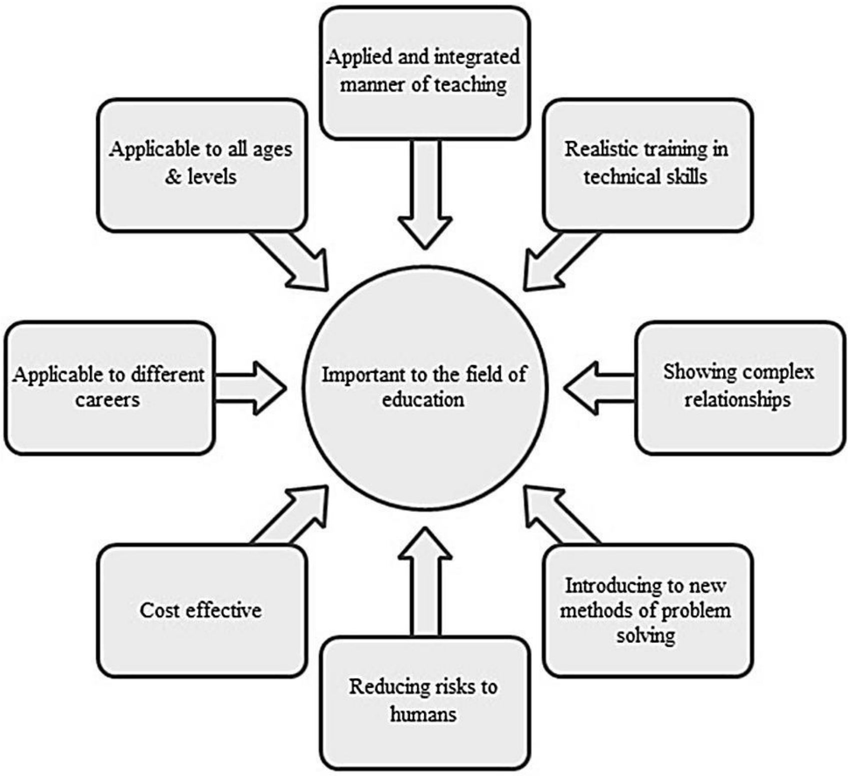

Figure 2: Reasons that make simulations important to the field of education

II. METHODS AND MATERIAL

This case study aimed to assess the potential of a virtual project-based simulation game in construction education when the target audience is students with limited experience in construction. In order to evaluate the research hypothesis, Skyscraper Simulator was tested via quantitative methods.

Table 1. Some of Research Projects Conducted to Investigate the Role of Simulation in Construction Education

Simulation	Functionality	Result
Web-Based simulation game (Agapiou, 2006)	- Delivering the management, practice and law syllabus - Teaching professional practice skills to undergraduate architecture students	- Complementary adjunct to traditional methods - Developing generic professional practice skills - Helping with understanding the contractual process - Helping with exercising professional judgment more effectively
Construction planning and scheduling (Forcael, Glagola, & González, 2011)	- Teaching linear scheduling concepts & techniques in a civil engineering course	- Helping with understanding of linear scheduling concepts - Helping with understanding of linear scheduling techniques
Virtual interactive construction education (J. Goedert, Rokooeisadabad, & Pawloski, 2012; J. D. Goedert, Pawloski, Rokooeisadabad, & Subramaniam, 2013; Rokooei, Goedert, & Weerakoon, 2014; Rokooei & Goedert, 2015)	- Placing learners in the full context of construction management - Transforming traditional subject-based lectures into project-based virtual interactive simulations using cyber-infrastructure - Creating opportunities to sequentially order the construction activities - Creating opportunities to select the required resources for each activity	- Engaging - Improving construction content knowledge - Improving the interest in construction, science, technology, engineering and mathematics - Effective for players with little construction knowledge - Effective for construction education
UPTown (Venter & Coetzee, 2013)	- Creating opportunities to discover the value of cooperative planning in the land use and transportation - Creating opportunities to explore aspects of the land use - transportation relationship - creating opportunities to practice working on complex problems in a collaborative teamwork environment	- Enhancing the achievement of learning outcomes - Helping with mastering the course subject matter - Creating opportunities to experience the benefits of collaboration with others with different objectives
Virtual construction simulator (Lee, Nikolic, & Messner, 2014)	- Teaching the decisions involved in planning & managing the project construction	- Engaging
Simulated global virtual team (Pienaar, Wu, & Adams, 2015)	- Teaching virtual teamwork skills exclusively through distance education	- Increasing the level of engagement - Helping with learning & practicing virtual teamwork skills - Developing non-discipline-oriented teamwork skills
PERFECT (Rokooei, Goedert, & Fickle, 2015)	- Improving education of interdisciplinary area of project management	- Increasing the project time management content knowledge

Skyscraper Simulator is a project-based simulation game that puts players in a virtual construction environment and directs them on how to manage skyscraper construction from the beginning to the end, through a number of help windows. The players should manage the sequential work of construction. They go through each activity and complete the sub-activities required. Their main tasks are to buy sufficient equipment, hire enough personnel, and assign the right number of them to each activity. Each decision immediately affects projects cost and duration, which are the criteria of project success. Making wrong decisions will result in either stopping the construction process or increasing the project cost or time. Players can see their decision outcomes since an indicator shows the time and funds throughout the game. Another indicator shows the percentage of progress in both the current stage and the whole construction process (Fig. 3). Moreover, some bars direct players through a sequence of decisions resulting in animated delivery of the construction machinery and construction of a skyscraper. Therefore, players can watch the gradual completion of the project, although they see no workforce throughout the game.

Figure 3: Cost and progress indicator

When a player starts playing, they see a City View in which properties can be bought, sold, and rented out. Some features of the chosen skyscraper can also be changed. The player can change the height, residential/office area percentage, and residential/office class in the design of a skyscraper (Fig. 4). In an information window, which opens after selecting the property, the most important attributes of the property are displayed.

The land's rank should be considered carefully since it determines the sort of skyscrapers which can be built on the property. After selecting the property, the player should click on the Buy button to acquire it. On the bottom center of the window, some buttons represent the properties the player owns. When the player selects one of the buttons, the property information and status window, in which the player can start constructing the skyscraper, appears. In the Construction View, the player should decide what sort of skyscraper they will build. Once per month, a part of the total cost of the skyscraper is deducted from the player's account depending on the progress which suggests a provisional monthly statement. If the player runs out of money, the game is over. Therefore, the player should not start with skyscrapers they don't have enough money to finish. In order to start construction, the player should switch into the Construction Site View.

In the Construction Site View, the player should manage the machinery and staff working in the construction site. The player should assign a certain amount of workforce to each machinery type and sufficient staff to every team. Through human resources, engineers, foremen, and workers can be hired and fired. If the player hires enough engineers and foremen, they will be automatically assigned to work on vehicles and teams; but, workers should be assigned manually in order to improve machinery or team performance.

Figure 4: The features which can or cannot be changed

The construction process is divided into three stages, including the excavation stage, foundation stage, and construction stage. Different machinery types and teams are required in each stage. At least one excavator and one dumper should be bought to start the excavation stage. In order to reduce monthly costs, enough workers should be assigned to the administration team. Some workers should be also assigned to the maintenance crew in order to reduce the risk of machinery breaking down. The number of workers needed on the maintenance crew is in direct proportion to the number of vehicles the player has.

Excavation is a relatively easy stage. The player should buy or sell excavators and dumpers and should assign workers to them in order to manage this stage. The larger the number of workers assigned to a vehicle, the better its performance. The player must keep the bars on the left side of the vehicles tab as full as possible in order to optimize excavation. The bars look full when the vehicles are working optimally. If the dump trucks work too fast, the excavator performance bar will not be full. In this situation, the player should either buy more excavators or assign more workers to existing ones. The same principle applies to all other vehicles. When the excavation stage is completed, the excavators and dump trucks can be sold in order to increase funds. They can also be transported to one of the other construction sites which the player owns.

For the foundation stage, concrete mixer trucks and a team of foundation builders are required. The bar next to the foundation team's performance bar represents the foundation concrete cache. Concrete mixer trucks transport concrete into this cache. If the cache is completely emptied, the team will enter wait mode. The concrete mixer trucks operations will be halted if the cache is completely filled. Now, the player can reassign the staff, previously assigned to excavation stage vehicles, to either the foundation builders or to each of the concrete mixer trucks. If the available workers or foremen are not enough, some more personnel should be hired through human resources. If some of them are not required, they should be fired.

After finishing the foundation stage, the player should manage the final construction stage. Concrete mixer trucks, transport trucks, Kangaroo cranes, steel structure and concrete floor teams are needed in this stage. Transport trucks transport materials such as steel beams to the lower steel cache. Then, cranes lift them to the upper steel cache on the top of the building. There, the materials are used by the steel structure team for building the skyscraper's frame. Concrete is transported to the lower concrete caches by using concrete mixer trucks. Then, it is lifted to the upper concrete cache by cranes. This cache is on the top of the building, where the concrete floor team uses it to build the skyscraper's floors. At this stage, enough engineers, foremen and workers should be available. Through human resources, more of them can be hired if needed. After finishing the skyscraper, all the remaining vehicles will be sold immediately. At this moment, the player should do nothing more on the construction site.

The case study research was designed into two sections. First, the participants played the game. Then, a survey was carried out. The game was tested by 135 construction students at the undergraduate level since the target audience for this study was construction students with limited experience in construction. Every participant had Skyscraper Simulator installed on their own laptop and was allowed enough time to manage the construction of one skyscraper from the beginning to the end, regardless of the number of times they might fail.

After completing one skyscraper, they completed a questionnaire and provided information about their age, gender, construction experience in years, and if they ever passed any courses in construction management. In order to measure the players' perception of knowledge gained, they were asked to complete a retrospective pre- and post-playing self-assessment, through the questionnaire. They rated their pre- and post- playing content knowledge for five construction areas on a five point Likert scale. In order to select the five subject areas, the researcher considered different subject areas typical for construction management curriculum (Pariafsai 2013). Then, they played the game in order to find which subject areas typical for construction management curriculum the game potential corresponded with. The following subject areas of construction management, which correlated with both the game and the curriculum, were then selected:

1. Construction stages and factors: stages, machinery, personnel, and factors interactivity.
2. Estimation: site costs, machinery costs, personnel costs, and key factors in capital management.
3. Machinery management: key factors in machinery provision, key factors in optimum use of machinery,

machinery management duties and machinery management goals.

4. Personnel management: key factors in personnel provision, key factors in optimum use of personnel, personnel management duties and personnel management goals.
5. Major steps in building a project: basic principles of excavation, basic principles of foundation construction, basic principles of steel structure building, and basic principles of concrete floor construction.

Moreover, the participants were asked to rate their retrospective pre- and post- playing ability or skill, which are critical in project management situations, including skill in conditions analysis, skill in decision-making, ability to understand project management concepts, and self-confidence in working as a project manager, on a five point Likert scale. They also answered a set of questions on a five point Likert scale to rate

- the information adequacy for making right decisions,
- the effectiveness of seeing the decision outcomes in learning,
- the extent to which they referred to the instructions for resolving either an ambiguity or a problem,
- the impact of the factors learning from mistakes, prior knowledge from academic, learning, prior knowledge from non-academic learning, and prior knowledge from professional experience on their performance,
- the degree to which they learned by doing,
- the degree to which the game provided opportunity to experience theoretical concepts,
- the extent to which the aim of wining motivated them to learn,
- the extent to which they were satisfied with what they learned,
- The degree to which the game was interesting,
- The extent to which they preferred competitive computer games to individual ones, and
- The extent to which they preferred learning through educational computer games to learning by studying books.

In order to process the collected data, participant responses were coded on a scale of 1 to 5, standing for not at all, just a little, somewhat, a lot, and a great deal, respectively and then were analysed using descriptive statistics including mean, standard deviation and frequency. The data, collected through retrospective pre- and post-playing self-assessment, was also analysed using a paired-samples T test to determine if there was a significant difference between the pre- and post- playing scores at a significance level of .05.

III. RESULTS AND DISCUSSION

The hypothesis of this research was that a project-based simulation game can be an effective learning tool for students with limited previous education in construction. 135 students from an undergraduate construction program including 66 females (48.9%) and 69 males (51.1%), participated in the test. Their mean experience in construction was less than 1 year ($\mu = 0.789$, $\sigma = 1.9326$) while 77% of them had no previous experience in construction. As shown in Fig. 5, the percentage of inexperienced females was higher than that of their male counterparts. In addition, 68.1% of the participants had some previous knowledge in project management through courses relevant to project management. A nearly equal percentage of both genders had passed such courses (70% of females and 67% of males). After completion of the game, students participated in a pilot test and implicitly responded to the hypothesis question, i.e. the effectiveness of a simulation game in construction education. In order to assess the players' opinions, a five-point Likert scale was used to quantify the responses. The Likert scale provided values 1, 2, 3, 4 and 5 for not at all, just a little, somewhat, a lot and a great deal respectively.

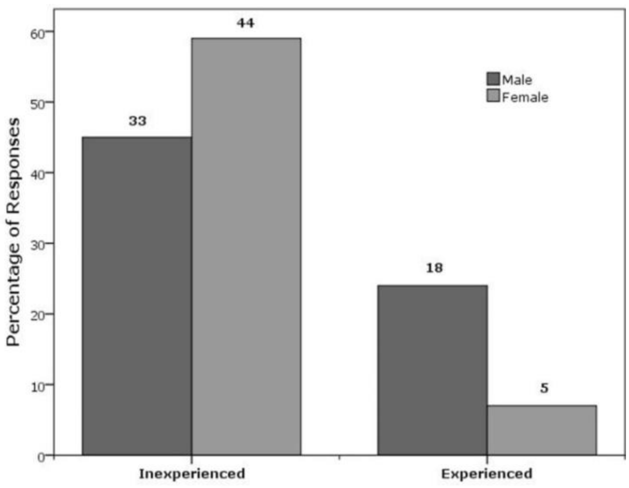

Figure 5: Different genders' construction background expressed as a percentage

In one question, the participants were asked to rate the information adequacy for making right decisions in the game. The responses mean and standard deviation (μ = 3.667, σ = 0.8011) indicate that they rated the sufficiency of information for right decision-making between somewhat and a lot on average. The highest percentage (43%) belongs to somewhat (Fig. 6). Only 3.7% of the students stated that it was not at all or just a little (0% and 3.7% respectively) whereas 53.3% of them reported that it was a lot or a great deal (36.3% and 17.0% respectively). In other words, the cumulative percentage of the levels a lot and a great deal (53.3%) is higher than that of the levels just a little and somewhat (46.7%), which means over half of the players agreed that the information was enough for making right decisions while playing.

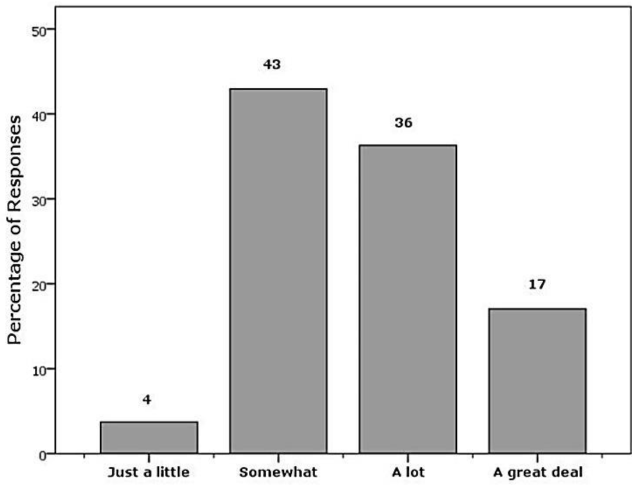

Figure 6: Percentage distribution for enough knowledge of results for making right decisions

In another question, the participants rated how effective "seeing the decision results" was in learning while playing. Table 2 presents the percentage of each level for all students. The responses mean and standard deviation (μ = 3.822, σ = 0.7999) indicate that the participants rated the positive impact of results seeing on learning between somewhat and a lot. The highest percentage (56.3%) belongs to the level a lot (Fig. 7). Moreover, only 5.2% of students reported that the impact was "not at all" or "just a little" whereas 72.6% of students mentioned the results seeing impacted learning while playing a lot or a great deal (56.3% and 16.3% respectively). This means that most students (94.8%) agreed with the positive impact of seeing their decision results on their learning while playing.

Table 2: Results of Rating Impact of Seeing Results on Learning

Question	Score	Percentage of Score
Impact of seeing results of decisions on learning	Not at all	1.5
	Just a little	3.7
	Somewhat	22.2
	A lot	56.3
	A great deal	16.3

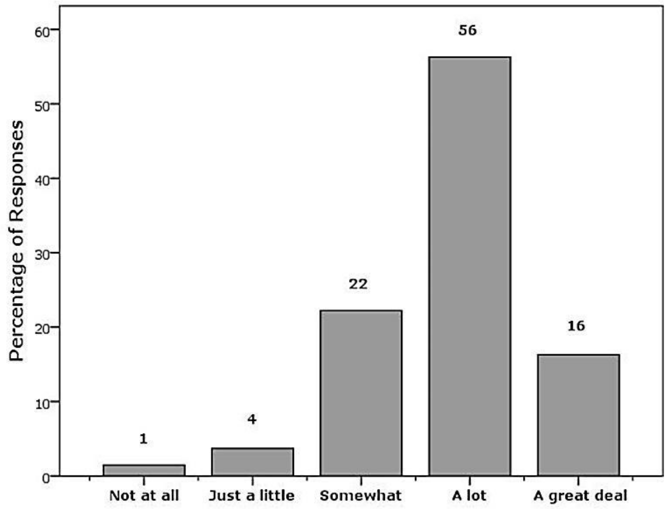

Figure 7: Percentage distribution for impact of seeing results of decisions on learning

Participants also rated to what extent they referred to the instructions for resolving an ambiguity or a problem when playing. Table 3 presents the percentage of each level of the five point Likert scale. The responses mean and standard deviation (μ = 2.615, σ = 1.1262) indicate the participants reported that they referred to the instructions between just a little and somewhat. 45.9% of students stated that they referred to the instructions while playing either not at all or just a little (20.0% and 25.9% respectively) whereas 23.7% of them reported that they did either a lot or a great deal (20.0% and 3.7% respectively). Furthermore, 20% of them rated referring to the instructions while playing not at all. Therefore, 80% of the participants referred to the instructions for resolving an ambiguity or a problem when playing and over half of all the participants (54.1%) found it helpful at least somewhat.

Table 3: Results of Rating the Extend of Referring to Instructions

Question	Score	Percentage of Score
Referring to instructions for fixing problems while playing	Not at all	20.0
	Just a little	25.9
	Somewhat	30.4
	A lot	20.0
	A great deal	3.7

In the other question, participants were asked to rate the impact of factors including trial and error, prior knowledge from academic learning, prior knowledge from non-academic learning and prior knowledge from professional experience on their performance in the game. As Table 4 shows, trial and error was rated as the most effective factor in learning how to play well.

Table 4: Results of Rating Impact of Different Factors on Performance

Impact of Different Factors on Success	Learning from Mistakes	Prior Academic Learning	Prior non-Academic Learning	Professional Experience
Mean: μ	3.437	2.689	2.807	2.444
Standard Deviation: σ	.9273	1.0891	1.1750	1.3139

Additionally, participants also rated how much they learned by doing in the game. In Table 5, the percentage of each level is shown. The mean and standard deviation of responses were $\mu = 3.622$ and $\sigma = 0.7905$. The highest percentage (49.6%) belongs to the level a lot (Fig. 8). Further, only 7.4% of students stated that they learned by doing not at all or just a little (0.7% and 6.7% respectively) whereas 60.0% of them reported that using new subjects simplified learning either a lot or a great deal (49.6% and 10.4% respectively). In other words, most students (92.6%) thought the game gave them the opportunity to experientially learn at least somewhat.

Table 5: Results of Rating Learning by Doing

Question	Score	Percentage of Score
Learning by doing	Not at all	0.7
	Just a little	6.7
	Somewhat	32.6
	A lot	49.6
	A great deal	10.4

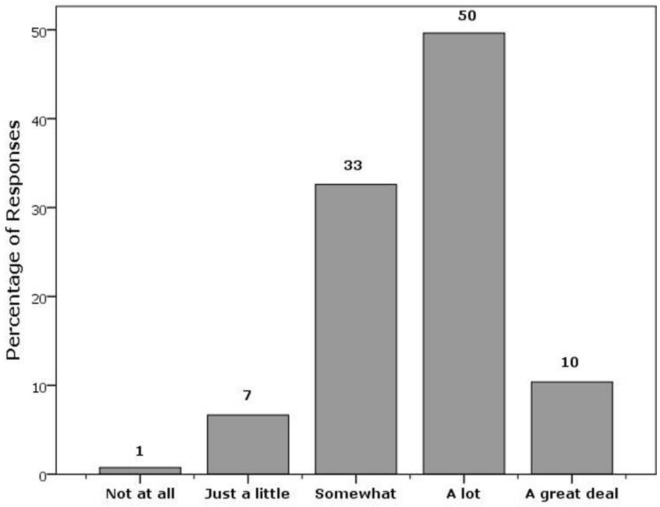

Figure 8: Learning by doing - Percentage distribution of responses

Participants were also asked to rate how much opportunity the game provided in order to experience theoretical concepts. Table 6 shows the percentage of each level of the five Likert scale. The responses' mean and standard deviation ($\mu = 3.578$, $\sigma = 0.9733$) indicate that the game gave the players a chance to experience theoretical concepts. The highest percentage (40%) relates to the level "a lot". In addition, only 11.1% of students rated the chance of experiencing the concepts not at all or just a little (3.7% and 7.4% respectively) whereas 56.3% of them reported that they had the chance to do it a lot or a great deal (40.0% and 16.3% respectively). The cumulative percentage of the levels somewhat, a lot and a great deal (88.9%) indicates most players thought that, when playing, they used what they had theoretically learned.

Table 6: Results of Rating Chance of Experiencing Concepts

Question	Score	Percentage of Score
Experience of theoretical concepts	Not at all	3.7
	Just a little	7.4
	Somewhat	32.6
	A lot	40.0
	A great deal	16.3

On the other hand, the players were asked to rate how much the aim of winning motivated them to learn while playing. According to the responses mean and standard deviation (μ = 4.059, σ = 0.8082), the participants felt their motivation for learning increased nearly a lot. The highest percentage (47.4%) belongs to the level 4 (Fig. 9) and only 2.9% of students rated "success in the game as learning motivation" not at all or just a little (0.7% and 2.2% respectively), whereas 78.5% of students reported their motivation for learning increased a lot or a great deal (47.4% and 31.1% respectively). This means most students were considerably motivated to learn while playing in order to score the best in the game.

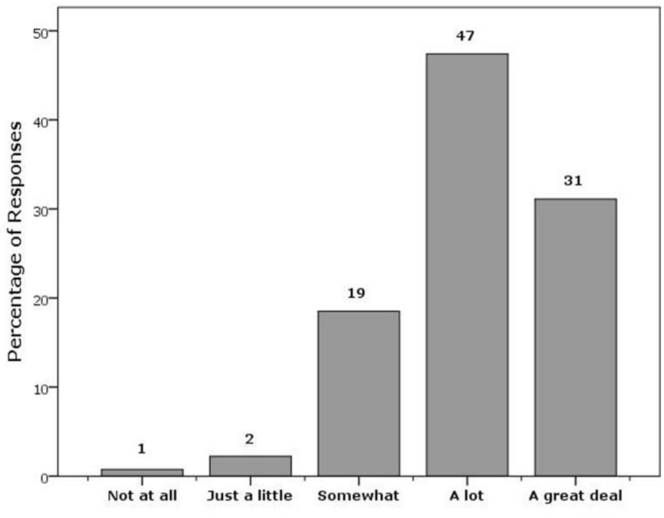

Figure 9: Increase in learning motivation - Percentage distribution of responses

The participants also rated their satisfaction of learning in the game. Table 7 shows the percentage of each level of the five Likert scale. The responses mean and standard deviation (μ = 3.815, σ = 0.8740) indicate that they were satisfied with the amount they learned in the game. The level a lot obtained the highest percentage (43.0%). In addition, only 7.4% of students stated they learned not at all or just a little (0% and 7.4% respectively) whereas 66% of students reported that through the game, they learned a lot or a great deal (43.0% and 23.0% respectively). In other words, 92.6% students were at least somewhat satisfied with the amount they learned through the game.

Table 7: Results of Rating Satisfaction of Learning

Question	Score	Percentage of Score
Satisfaction of learning	Not at all	0.0
	Just a little	7.4
	Somewhat	26.7
	A lot	43.0
	A great deal	23.0

In another question, students rated how interesting the game was in their opinion. Table 8 shows the percentage of each level. The responses mean and standard deviation (μ = 3.852, σ = 0.9737) indicates that they rated it fun. The highest percentage belongs to the level a lot (37.0%) and only 7.4% of students found it either not at all or just a little interesting (2.2% and 5.2% respectively) whereas 65.9% of them reported that it was either a lot or a great deal interesting (37% and 28.9% respectively). In other words, the results indicate that 92.6% of students enjoyed playing the game at least somewhat.

Table 8: Results of Rating How Much Fun to Play

Question	Score	Percentage of Score
Interesting and fun to play	Not at all	2.2
	Just a little	5.2
	Somewhat	26.7
	A lot	37.0
	A great deal	28.9

The players were also asked to rate how much they preferred competitive computer games to individual ones. Table 9 presents the percentage of each level of the five Likert scale. According to the responses mean and standard deviation (μ = 3.467, σ = 1.2020), they preferred competitive computer games to individual ones. The highest percentage (30.4%) belongs to the level somewhat (Fig. 10). Only 20.8% of students stated that they preferred competitive ones either not at all or just a little (6.7% and 14.1% respectively) whereas 48.9% of them reported that they preferred competitive computer games a lot or a great deal (23.7% and 25.2% respectively). The cumulative percentage of the levels somewhat, a lot and a great deal (79.3%) means that most students preferred competitive computer games to individual ones more than just a little.

Table 9: Results of Rating Preference for Competitive Computer Games

Question	Score	Percentage of Score
Competitive computer games in preference to individual computer games	Not at all	6.7
	Just a little	14.1
	Somewhat	30.4
	A lot	23.7
	A great deal	25.2

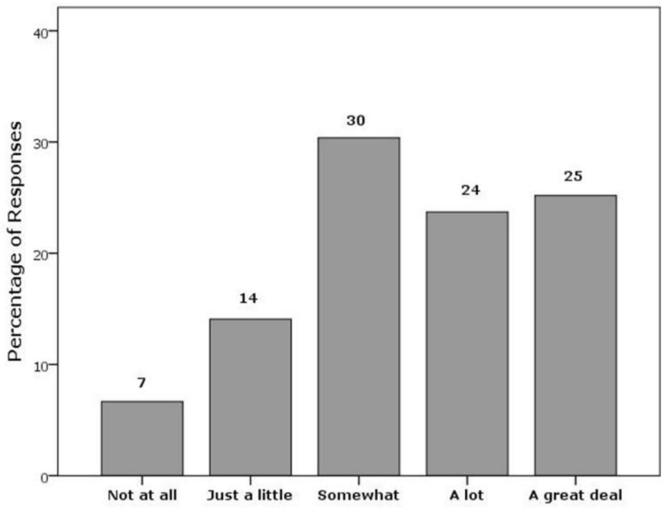

Figure 10: Percentage distribution of preference for competitive games

The participants were also rated how much they preferred learning through educational computer games compared to learning through studying books. The responses mean and standard deviation ($\mu = 4.104$, $\sigma = 0.8833$) indicate that the participants preferred educational computer games to books. Only 2.9% of students stated that they preferred the games to the books either not at all or just a little (0.7% and 2.2% respectively) whereas 74.1% of students reported that they preferred to learn by means of the games than books either a lot or a great deal (34.1% and 40% respectively) (Fig .11). The results indicate that most students (97.1%) prefer to learn by playing instead of studying.

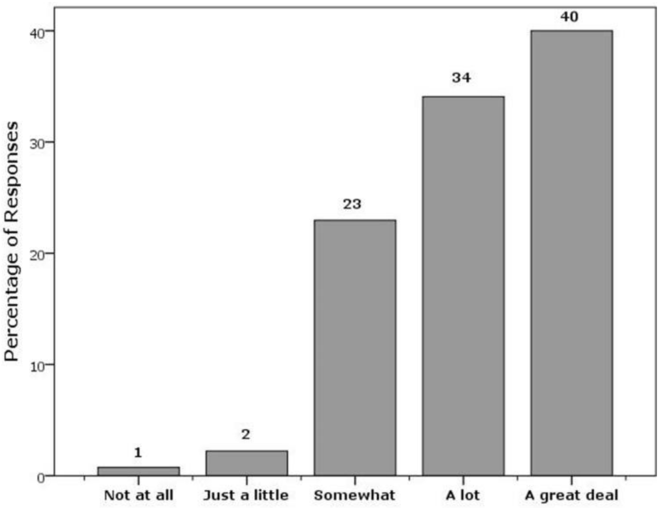

Figure 11: Percentage distribution of preference for educational games

Students also rated their knowledge, ability, and skills both before and after playing the simulation by answering a question, which was split into the following six areas:

1) Construction stages and factors including:
    a. Knowledge about construction stages
    b. Knowledge about construction machinery
    c. Knowledge about construction personnel
    d. Knowledge about different construction factors interactivity
2) Estimation including:
    a. Knowledge about construction site costs
    b. Knowledge about construction machinery costs
    c. Knowledge about construction personnel costs
    d. Knowledge about key factors in capital management
3) Machinery management including:
    a. Knowledge about key factors in machinery provision
    b. Knowledge about key factors in optimum use of machinery
    c. Knowledge about machinery management duties
    d. Knowledge about machinery management goals

4) Personnel management including:
    a. Knowledge about key factors in personnel provision
    b. Knowledge about key factors in optimum use of personnel
    c. Knowledge about personnel management duties
    d. Knowledge about personnel management goals
5) Ability and skills including:
    a. Skill in conditions analysis
    b. Skill in decision-making
    c. Ability to understand project management concepts
    d. Self-confidence in taking project manager responsibilities
6) Major steps in building a project including:
    a. Knowledge about basic principles of excavation
    b. Knowledge about basic principles of foundation construction
    c. Knowledge about basic principles of steel structure building
    d. Knowledge about basic principles of concrete floor construction

The responses for the question were analysed using descriptive statistics including mean (μ), standard deviation (σ), and frequency (Table 10). The self-reported evaluation data on each of these areas were compared by means of a paired-samples T test. The paired-samples T test indicates that there was a significant difference between the mean scores of pre-playing and post-playing situations at a 0.05 significance level ($\alpha=0.05$) for all areas (Table 11).

Table 10: Paired-Samples T Test Results for Each Pair of Construction Main Areas Questions

Paired Samples			Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Construction Stages Knowledge	Pre	2.926	135	.9274	.0798
		Post	3.978	135	.7172	.0617
Pair 2	Construction Machinery Knowledge	Pre	2.867	135	.9447	.0813
		Post	3.911	135	.7961	.0685
Pair 3	Construction Personnel Knowledge	Pre	2.630	135	.8702	.0749
		Post	3.726	135	.8676	.0747
Pair 4	Construction Factors Interactivity Knowledge	Pre	2.341	135	.8908	.0767
		Post	3.659	135	.8301	.0714
Pair 5	Construction Site Costs Knowledge	Pre	2.133	135	.8961	.0771
		Post	3.578	135	.7961	.0685
Pair 6	Construction Machinery Costs Knowledge	Pre	2.104	135	.9870	.0850
		Post	3.430	135	.8939	.0769
Pair 7	Construction Personnel Costs Knowledge	Pre	2.407	135	.9872	.0850
		Post	3.630	135	.8529	.0734
Pair 8	Capital Management Key Factors Knowledge	Pre	2.037	135	.9574	.0824
		Post	3.363	135	.9589	.0825
Pair 9	Machinery Provision Key Factors Knowledge	Pre	1.993	135	.9183	.0790
		Post	3.304	135	.9165	.0789
Pair 10	Optimum Use of Machinery Knowledge	Pre	2.022	135	.9733	.0838
		Post	3.519	135	.8882	.0764
Pair 11	Machinery Management Duties Knowledge	Pre	2.222	135	.9277	.0798
		Post	3.541	135	.9365	.0806
Pair 12	Machinery Management Goals Knowledge	Pre	2.274	135	1.0106	.0870
		Post	3.570	135	.9738	.0838
Pair 13	Personnel Provision Key Factors Knowledge	Pre	2.244	135	.8849	.0762
		Post	3.526	135	.9210	.0793
Pair 14	Optimum Use of Personnel Knowledge	Pre	2.267	135	.9240	.0795
		Post	3.563	135	.9273	.0798

Pair 15	Personnel Management Duties Knowledge	Pre	2.422	135	.9885	.0851
		Post	3.704	135	.9230	.0794
Pair 16	Personnel Management Goals Knowledge	Pre	2.422	135	1.0400	.0895
		Post	3.652	135	.9249	.0796
Pair 17	Conditions Analysis Skill	Pre	2.222	135	.8950	.0770
		Post	3.615	135	.8723	.0751
Pair 18	Decision-Making Skill	Pre	2.519	135	.9989	.0860
		Post	3.993	135	.8331	.0717
Pair 19	Understanding Project Management Concepts	Pre	2.400	135	1.0236	.0881
		Post	3.778	135	.8256	.0711
Pair 20	Project Manager Self-Confidence	Pre	2.652	135	1.2538	.1079
		Post	4.015	135	.8976	.0773
Pair 21	Excavation Principles Knowledge	Pre	2.800	135	1.0424	.0897
		Post	4.059	135	.8082	.0696
Pair 22	Foundation Construction Principles Knowledge	Pre	2.785	135	1.0029	.0863
		Post	3.993	135	.8852	.0762
Pair 23	Steel Structure Building Principles Knowledge	Pre	2.674	135	1.1119	.0957
		Post	3.874	135	.9258	.0797
Pair 24	Concrete Floor Building Principles Knowledge	Pre	2.570	135	1.0827	.0932
		Post	3.733	135	.9240	.0795

Table 11: Paired-Samples T Test Results of Pre- and Post- Playing Comparison

Paired Samples			Paired Differences					t	df	Sig. (2-tailed)
			Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
						Lower	Upper			
P_1	Construction Stages Knowledge	Pre	-1.0519	.8315	.0716	-1.1934	-.9103	-14.699	134	.000
		Post							134	.000
P_2	Construction Machinery Knowledge	Pre	-1.0444	.8540	.0735	-1.1898	-.8991	-14.210	134	.000
		Post							134	.000
P_3	Construction Personnel Knowledge	Pre	-1.0963	.7519	.0647	-1.2243	-.9683	-16.942	134	.000
		Post							134	.000
P_4	Construction Factors Interactivity Knowledge	Pre	-1.3185	.8780	.0756	-1.4680	-1.1691	-17.448	134	.000
		Post							134	.000
P_5	Construction Site Costs Knowledge	Pre	-1.4444	.8523	.0734	-1.5895	-1.2994	-19.692	134	.000
		Post							134	.000
P_6	Construction Machinery Costs Knowledge	Pre	-1.3259	.8180	.0704	-1.4652	-1.1867	-18.834	134	.000
		Post							134	.000

P_7	Construction Personnel Costs Knowledge	Pre	-1.2222	.7694	.0662	-1.3532	-1.0912	-18.456	134	.000
		Post							134	.000
P_8	Capital Management Key Factors Knowledge	Pre	-1.3259	.8795	.0757	-1.4756	-1.1762	-17.516	134	.000
		Post							134	.000
P_9	Machinery Provision Key Factors Knowledge	Pre	-1.3111	.8679	.0747	-1.4588	-1.1634	-17.553	134	.000
		Post							134	.000
P_{10}	Optimum Use of Machinery Knowledge	Pre	-1.4963	.9532	.0820	-1.6586	-1.3340	-18.239	134	.000
		Post							134	.000
P_{11}	Machinery Management Duties Knowledge	Pre	-1.3185	.8344	.0718	-1.4606	-1.1765	-18.359	134	.000
		Post							134	.000
P_{12}	Machinery Management Goals Knowledge	Pre	-1.2963	.8731	.0751	-1.4449	-1.1477	-17.251	134	.000
		Post							134	.000
P_{13}	Personnel Provision Key Factors Knowledge	Pre	-1.2815	.7979	.0687	-1.4173	-1.1457	-18.662	134	.000
		Post							134	.000
P_{14}	Optimum Use of Personnel Knowledge	Pre	-1.2963	.8382	.0721	-1.4390	-1.1536	-17.969	134	.000
		Post							134	.000
P_{15}	Personnel Management Duties Knowledge	Pre	-1.2815	.9436	.0812	-1.4421	-1.1209	-15.780	134	.000
		Post							134	.000
P_{16}	Personnel Management Goals Knowledge	Pre	-1.2296	.8547	.0736	-1.3751	-1.0841	-16.716	134	.000
		Post							134	.000
P_{17}	Conditions Analysis Skill	Pre	-1.3926	.9231	.0795	-1.5497	-1.2355	-17.528	134	.000
		Post							134	.000
P_{18}	Decision-Making Skill	Pre	-1.4741	.9837	.0847	-1.6415	-1.3066	-17.412	134	.000
		Post							134	.000
P_{19}	Understanding Project	Pre	-1.3778	.9915	.0853	-1.5466	-1.2090	-16.145	134	.000

	Management Concepts	Post							134	.000
P_{20}	Project Manager Self-Confidence	Pre	-1.3630	1.0481	.0902	-1.5414	-1.1845	-15.109	134	.000
		Post							134	.000
P_{21}	Excavation Principles Knowledge	Pre	-1.2593	.9847	.0847	-1.4269	-1.0916	-14.859	134	.000
		Post							134	.000
P_{22}	Foundation Construction Principles Knowledge	Pre	-1.2074	.9312	.0801	-1.3659	-1.0489	-15.066	134	.000
		Post							134	.000
P_{23}	Steel Structure Building Principles Knowledge	Pre	-1.2000	.9910	.0853	-1.3687	-1.0313	-14.069	134	.000
		Post							134	.000
P_{24}	Concrete Floor Building Principles Knowledge	Pre	-1.1630	.9941	.0856	-1.3322	-.9937	-13.593	134	.000
		Post							134	.000

The results of the pilot test indicate that there is a statistically significant difference between the retrospective pre and post perception of construction management knowledge, ability, and skills in all six areas, which shows that Skyscraper Simulator provided an effective learning environment in construction education.

IV.CONCLUSION

This research study indicated the great potential of a virtual project-based simulation game as a part of construction education and learning strategies. Most participants preferred learning by playing to studying, albeit to different degrees, despite preferring competitive computer games to individual ones. The virtual project-based simulation game was interesting and efficient, thus turning the learning process into an enjoyable motivating experience. When playing, the learners could practice construction operational and management skills and learn from mistakes unacceptable in real world situations, where any small mistake could result in serious technical, financial, or safety results. However, unlike real world situations, in simulation environment "Learning from Mistakes" was rated as the most effective method of learning.

The virtual project-based simulation game provided learners with the contexts to practically experience theoretical concepts while giving enough performance feedback required for making right decisions. Visualizing the decision outcomes in situations which might be encountered in real construction sites helped the students with learning. The instructions also helped learners when facing an ambiguity or a problem. Moreover, the game improved the students' understanding of project management and their analytical thinking and decision-making abilities. It also increased their self-confidence in Working as a Project Manager. Playing the game developed the students' knowledge, ability, and skills in a degree which satisfied them which indicates that the virtual project-based simulation game provided an effective learning environment in construction education.

Construction sites may be unavailable, at risk of dangerous situations, or too costly to be extensively visited by construction students. Furthermore, the whole construction process cannot be seen in the visiting time period, whereas project-based simulation games provide students with construction experience by virtually placing them in construction sites where students can see the whole construction process in a relatively short time. Through such simulations, students can test alternative strategies and observe the outcomes in risk-free environments. In this way, these games help students with learning through success and failure without undesirable real world consequences. Additionally, realistic tasks mirrored in project-based simulation games challenge students' critical thinking and problem-solving abilities and provide them with skills applied in real world situations. Since project-based simulation games have great potential for helping undergraduate construction students with learning, they should be pursued in construction education.

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