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Simulation as Supplementary Tool in Construction Management Education

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Abstract

Many academic programs utilize simulation applications to supplement higher education, but there are only a few applications responding to the need in construction curricula, particularly with a focus on project management. Project management is an interdisciplinary area of study, crosscutting multiple fields including the construction, information technology, and business sectors. This paper presents the design, development, and test of a research project entitled Project-oriented Educational Research Fostering Excellence in Cyber-infrastructure Teaching (PERFECT). It investigates the effect of a construction project management simulation on construction management students' engagement and perceptions at the University of Nebraska-Lincoln.

The goal of PERFECT was to develop and study the efficacy of a simulation for construction project time management. This is a common knowledge area in the Project Management Body of Knowledge (PMBOK) standard published by the Project Management Institute (PMI). PERFECT was a pilot module created in a simulated environment and allowed students to be interactively engaged in time management-related processes. Participants played the role of a project manager and were required to make management decisions throughout the simulation. Processes like input, tools and methods, and outputs in PERFECT were designed in accordance with the PMBOK standard. The fully developed application was tested with two groups of 30 construction students: the first group included students with prior project time management knowledge (Group A) whereas the second group consisted of students without any prior knowledge (Group B). The students' data were captured and retrieved automatically without any human interaction. A quantitative research method was used for analyzing the data and a retrospective post- survey was conducted to obtain participants' perceptions of the application. The results indicated the effectiveness of PERFECT and supported the expansion and further development of similar simulation applications. This type of evidence-based learning system not only enhances the validity and

reliability of the application, but has a potential for incorporation into the academic arena particularly in construction.

Introduction

New advancements in technology have changed the education environment. Different programs are incorporating technological methods to promote research and teaching in academia and provide instructors with a set of practical and effective tools to facilitate the learning process. Various research projects have shown the effectiveness of technological tools in education (Department of Education, 2014). The advent of gaming and 3D modeling has enabled educators to utilize computer-based learning activities and mingle engaging 3D graphical features with traditional learning approaches. One of these technological tools are the simulation applications that are being used in higher education. According to Aldrich (2003), simulations are defined as "tools that allow users to learn by practicing in a repeatable, focused environment." Simulations navigate students through a series of predefined scenarios and provide them with a set of purposeful informative modules. When the provided information reaches to a measurable threshold, the applications require students to interactively communicate with the system and simulate a real-world situation. The results are displayed to students so that they are able to revise their decisions and improve the outcomes. This process can be repeated several times and thus each iteration enhances students' learning by showing a sequence of 'what-if' conditions and their outcomes.

Engineering programs, along with other fields such as business, medical science, and military-related programs, strive to develop applications to exploit the advantages of simulations. However, construction engineering and management programs have been less prone to adopting simulations in their curricula. So far, only a few instances of simulation application have been developed and tested in construction programs, therefore there is a need to fill this gap. This paper explores the outcomes of a simulation application as a project-based pedagogical model, and investigates how construction project management concepts can be perceived by construction management students. Transformation of traditional subject-based lectures of construction project management to project-based, virtual, interactive simulations was performed through a series of educational modules, videos, pictures, audios, and animations. To appraise the inputs, processes, and outputs of the simulation application, the research questions were defined as follows:

- How do students perceive the application and its features?
- How do students' perception and their actual performance relate to each other?

Evaluation of application effectiveness was performed via two approaches; first, the actual performance of students was measured by using a quasi-experimental interval, and second, a perceived content knowledge measurement was performed with a retrospective survey that asked students to rate their level of construction project management knowledge before and after simulations.

Literature review

The advent of simulation for educational purposes extends back several decades, however, during this period its presence in education has fluctuated (Harper, Squires, & Mcdougall, 2000). Technological advancement in multimedia, graphical software, and communication was a major catalyst toward adoption into the educational processes. Simulations have some unique characteristics that make them both effective and efficient in education. Simulations are typically used to decrease the time and cost of learning, and mitigate associated risks in the learning processes. Aviation and medical science are ideal fields for such applications (Hahn, 2010) and, thus, simulations have become essential in those areas with a myriad of robust educational tools being effectively utilized in different forms and styles. Okuda et al. (2009) addressed the role and importance of simulations in medical education in different fields including basic science, physical examination, clinical clerkships, skills training, anesthesiology, surgery, obstetrics, emergency medicine, pediatrics, and critical care at undergraduate and graduate levels. However, the use of simulations in education has not been confined to these aforementioned fields. Currently, various fields of study have started to embed simulation in their curricula including politics (Starkey & Blake, 2001), entrepreneurship (Wolfe & Bruton, 1994), nursing (Aebersold & Tschannen, 2013), engineering (Smith & Pollard, 1986), and psychology (Künzel & Hämmer, 2006).

Simulation and educational games possess their own strengths and weaknesses. Knowing the capabilities and shortcomings of simulations helps educators to effectively plan, develop, and implement them. One of the main advantages of using simulations in education is providing real time feedback. In fact, the whole system is designed such that every decision that students make is the beginning of a learning process that triggers subsequent reactions or events. Through this cycle, feedback is continuously generated and displayed. Having the logic of decisions in mind and experiencing the results students can connect the dots and follow an instruction flow (Rokooei, 2016). Simulation applications are also being utilized in abstract environments and hence the associated educational risks and costs are considerably decreased (Craig, 1996). Selecting and experiencing different scenarios in simulations is another potential feature that enables students to learn by comparing the consequences of different options. This improves the quality of leaning while minimizing educational costs, time and risks.

The value of simulations are many, but there are a number of shortcomings as well. For example, simulations are vulnerable to errors caused by unintentional interactions. Any wrong key stroke may confuse the user and change the simulation outcomes (Craig, 1996). In addition, simulation applications' dependence on specific software or hardware may limit its comprehensibility and result in inconsistency. Moreover, limited duration of simulation application makes it hard to provide a vast scope of a subject deeply and effectively. Another major issue in simulation applications is the evaluation method. Although this is a common problem in almost every educational tool, an evaluation method should be carefully designed through the simulation development process (Harteveld, 2012).

Despite the growth of simulation applications in many engineering fields, construction programs have not proportionally utilized simulation applications. There have been a few applications developed and used in areas related to construction management in recent decades. Simulation application instances that are developed and used for educational purposes include Contract & Construct (Martin, 2000), Project Management Trainer – PMT (Davidovitch, Parush, & Shtub, 2006), Multi-agent framework for situational simulations (Rojas & Mukherjee, 2005), MERIT (Wall & Ahmed, 2008), Virtual Construction Simulator 3 (Nikolić, 2011), SimProject (Szot, 2013), and VICE (Goedert et al., 2013). These simulations typically focus on one aspect of construction or project management and navigate students through a series of activities in which educational contents are provided. Although the outcomes of these applications indicate their success and effectiveness in educational environments, no standard evaluation procedure has been designed, and self-assessment has remained the major method for evaluation of simulation effectiveness.

Methodology

PERFECT was part of a research project designed in Durham School of Architectural Engineering and Construction to investigate the use of simulation applications in construction programs. The main objective of this paper is to illustrate the perception of construction students on this newly developed construction project management simulation (PERFECT). The research question in this study was "how do construction students perceive simulation applications and what factors impact their perceptions?" While the effectiveness of PERFECT is shown in another publication (Rokooei, Goedert, & Najjar, 2017), this paper reports on results from the survey. Based on previous experiences in design, development, and testing simulation applications, the general layout of the application was structured to include three instruments: Pre-Quiz, main simulation, and Post-Survey. Main simulation is the core of the application in which instructional contents are provided through educational modules and interactive elements.

Educational modules presented construction project time management concepts, tools, and methods. The flow of knowledge contents follows the PMBOK standard so that after a general section, PMI's project time management processes were presented. These processes included plan schedule management and define activities, sequence activities, estimate activities resources, estimate activities duration, develop schedule, and control schedule. Each process was illustrated through a different section and its inputs, tools and methods, and outputs were completely described. Interactive modules provided related audio/graphical contents in different sections. A combination of educational modules and interactive elements engaged students throughout the simulation and navigated them to the end of the simulation. In addition, knowledge-gained questions were embedded in different sections. This furnished the actual performance of participants and acted as an indicator for the knowledge gained. To show any difference between "pre" and "post" situations, a Pre-Quiz was designed to establish a baseline and examine the knowledge of students in areas similar to what was presented in the main simulation. The difference between the Pre-Quiz and the main simulation revealed the effectiveness of the simulation (Appendix A). In addition, a self-evaluation method was designed to investigate students' perceptions. This is a commonly accepted method to show the simulation effectiveness. Combined with the actual performance appraisal, it can reliably show the simulation's effectiveness. The self-evaluation process was designed in the form of a Post-Survey in which students rated different factors and expressed their opinions on various subjects related to the construction project management simulation.

A Likert-type scale questionnaire, developed by the researcher, was used to gather and quantify the data. The majority of data were collected through a series of questions asking the participants to rate various statements on their perceptions of using simulation on a 5-point scale in which 1 denoted "strongly disagree" against 5 as "strongly agree." The Post-Survey had four sections including demographic, interests, knowledge contents, and opinion questions. Then, collected data were analyzed using appropriate descriptive and inferential statistical tools. The results are discussed in the next section.

Data collection and analysis

PERFECT was tested with two groups of 30 construction students. In order to eliminate confounding factors and investigate the effectiveness of simulation, participants were selected such that one group was familiar with construction project time management concepts and the other one had no formal construction project time management training. Thus, Group A, which had prior knowledge, included senior and junior construction students while Group B mostly consisted of freshman students. The majority of both groups were male students (93%).

Previous Virtual Learning Experience:

Previous encounters with virtual learning or educational simulation applications can influence students' perceptions about the impact and capabilities of simulations and help them to embrace these tools rapidly. Although a majority of both groups did not have previous experience with simulation applications, Group B indicated more unfamiliarity, as shown in Table 1.

Table 1: Previous virtual learning experience

	Previous Experience with Virtual Learning and Simulation (%)	
	Yes	No
Group A	47	53
Group B	33	67

Increase of Interest in Construction Project Management by Playing the Simulation:

Participants in both groups also rated if their interests in Construction and Project Management had increased after interacting simulation. A five-point Likert scale was used in which 1 to 5 denoted a spectrum from “Totally Disagree” to “Totally Agree,” respectively. Percentages of each level of agreement is shown in Figure 1.

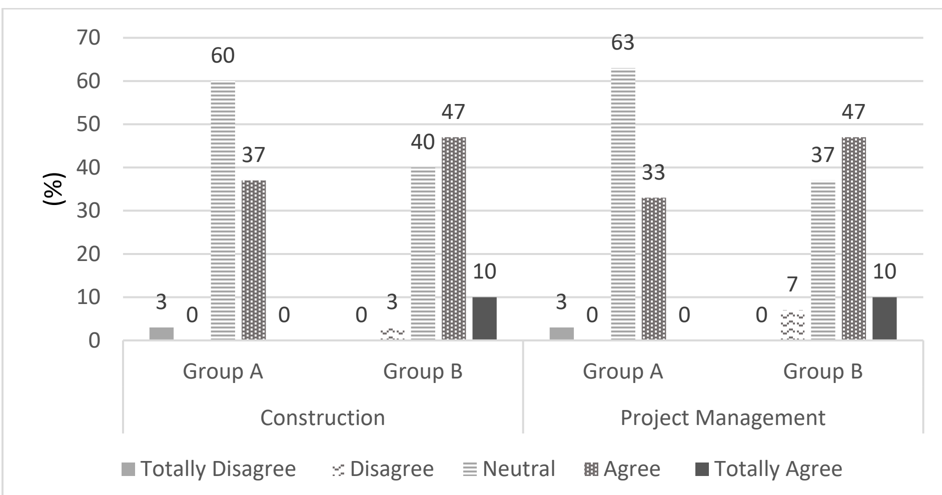

Figure 1: Effect of simulation on interest in construction and project management

Factors Impacting Students’ Performance:

Participants also rated the impact of various factors including “Prior knowledge from experience,” “Prior knowledge from classroom instruction,” “Instructions within the simulation,” and “Learning from my mistakes” on their performance throughout the simulation. Among the factors, “learning from mistakes” scored the highest percentage. This indicated repeatability as a unique feature of simulation because it enables students to learn from their own wrong decisions. Percentages of each level as well as average weight of each factor for two groups are shown in Table 2.

Table 2: Sources of impact on performance in Groups A & B

	Prior knowledge from experience		Prior knowledge from classroom instruction		Instructions within the simulation		Learning from mistakes	
	Group A	Group B	Group A	Group B	Group A	Group B	Group A	Group B
Excellent help (%)	7	10	13	10	0	7	20	23
Much help (%)	23	20	47	47	33	50	33	54
Some help (%)	60	37	27	20	47	40	40	20
A little help (%)	0	33	13	20	13	3	7	3
No help (%)	10	0	0	3	7	0	0	0
Average Weight	3.17	3.07	3.6	3.4	3.07	3.6	3.67	3.97

Impact of Simulation on the Learning Process:

In a section of the Post-Survey, participants were asked to express their opinions on different items regarding their learning process on a 5-level scale. First they rated to what extent simulation applications can help understand real-world problems. Table 3 shows the percentage of each level for Groups A and B.

Table 3: PERFECT help in learning real-world project time management

	Group A	Group B
No help (%)	13	0
A little help (%)	3	13
Some help (%)	54	40
Much help (%)	30	40
Excellent help (%)	0	7

In addition, participants rated the statement “I find simulation instruction to be a more effective learning tool than traditional lectures.” Figure 2 shows the percentage of each level for Group A and Group B.

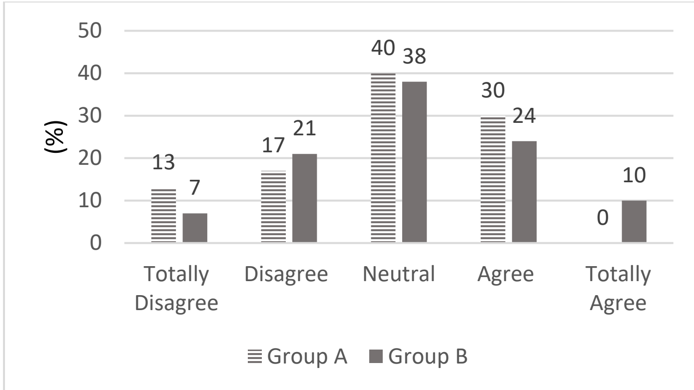

Figure 2: Simulations are more effective than traditional lectures

Participants were also asked to rate their level of engagement. As shown in Table 4, both groups showed an above-average level of engagement.

Table 4: Level of engagement

	Group A	Group B
No help (%)	7	0
A little help (%)	20	20
Some help (%)	39	40
Much help (%)	27	37
Excellent help (%)	7	3
Mean	3.07	3.23
Standard Deviation	1	. 80

In response to another question, participants rated how much they thought could be learned about project time management through simulation on a 5-point level scale. The percentage of each agreement level is shown in Figure 3.

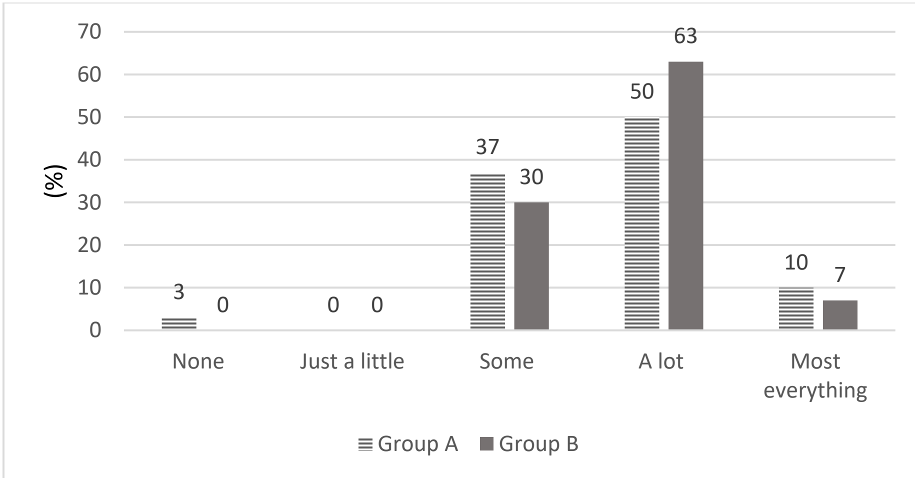

Figure 3: Learning project management through simulation

In the last question, participants were asked if they believed simulation-based learning should be integrated throughout the construction program. Participants' responses were rated on a 5-point level scale, as shown in Table 5.

Table 5: Integration of simulation-based learning throughout construction curricula

	Group A	Group B
Totally Disagree (%)	10	3
Disagree (%)	17	17
Neutral (%)	47	30
Agree (%)	23	43
Totally Agree (%)	3	7

Conclusion

PERFECT was shown to be an effective and engaging supplementary tool to support learning project time management in construction education. Tools like Pre-Quiz, main simulation, and Post-Survey were utilized to determine the level of participant engagement and effectiveness of the intervention. Two groups were established in order to minimize the effect of confounding variables. Group A had previous knowledge and familiarity of the content (project time management) while Group B did not have prior project time management knowledge. The majority of both groups did not have any previous virtual learning experience which seems a great opportunity for construction educators to incorporate simulation applications as one of their educational tools. While both groups of students expressed increased interest in construction and project management after interacting with the simulation, Group B showed a more diverse and intense level of engagement. Another major outcome of this experiment was recognizing factors that impacted the performance of students. Considerable difference between the average weight of “learning from mistakes” and other factors makes simulation an effective tool that can be used repeatedly so that through each round students have the opportunity of learning a new concept.

This unique feature of simulation applications allows students to see the consequences of their decisions, regardless of the correctness of those decisions and learn from the process. Obviously, both wrong and right decisions have some specific consequences which can be readily displayed to the students and hence convey the educational contents. Although there was a difference between the percentages of each agreement level for the two groups in responding to Post-Survey questions, both displayed a similar pattern for all questions. For example, both groups expressed a high level of agreement regarding the potential help of PERFECT in learning real-world project time management. In comparison of virtual learning and traditional lectures, students showed a positive consideration to the former. They also stated their high level of agreement with the potential of simulation applications in learning construction project time management, and therefore their agreement with integrating simulation-based learning throughout construction curricula.

Although this simulation proved its effectiveness in construction education, there are many features and traits that can be improved. Such recommendations are the results of researchers’ observations, experiences, and feedback received from participants. These include specifying the focus of simulation, designing an intricate simulation flow, providing different levels of difficulty for different users, enhancing interactive patterns, and establishing standard sets of measurement. All these suggestions can greatly improve the engagement level and effectiveness of the simulation. Future modules of PERFECT can cover other areas of project management knowledge such as cost, risk, scope, and quality. PERFECT can also deploy different roles and levels of control throughout simulation for students.

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Appendix A

Group A and B actual performance paired samples t-test

Groups	pairs		Paired Differences					t	df	Sig. (2-tailed)
			Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
						Lower	Upper			
A	Pair 1	aPost - aPre	.840	1.273	.073	.695	.985	11.432	299	.000
	Pair 2	bPost - bPre	.553	1.222	.071	.415	.692	7.846	299	.000
	Pair 3	cPost - cPre	.837	1.385	.089	.661	1.014	9.366	239	.000
	Pair 4	dPost - dPre	.470	1.093	.067	.339	.601	7.072	269	.000
B	Pair 1	aPost - aPre	.837	1.323	.076	.686	.987	10.957	299	.000
	Pair 2	bPost - bPre	.813	1.467	.085	.647	.980	9.602	299	.000
	Pair 3	cPost - cPre	.700	1.548	.100	.503	.897	7.007	239	.000
	Pair 4	dPost - dPre	1.085	1.413	.086	.916	1.254	12.620	269	.000

Appendix B

Group A and B self-evaluation paired samples t-test

Groups	pairs		Paired Differences					t	df	Sig. (2-tailed)
			Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
						Lower	Upper			
A	Pair 1	aPost - aPre	.367	.615	.112	.137	.596	3.266	29	.003
	Pair 2	bPost - bPre	.033	.490	.089	-.150	.216	.372	29	.712
	Pair 3	cPost - cPre	.167	.461	.084	-.006	.339	1.980	29	.057
	Pair 4	dPost - dPre	.200	.484	.088	.019	.381	2.262	29	.031
B	Pair 1	aPost - aPre	1.133	.900	.164	.797	1.469	6.901	29	.000
	Pair 2	bPost - bPre	.900	.885	.162	.570	1.230	5.572	29	.000
	Pair 3	cPost - cPre	.767	.858	.157	.446	1.087	4.892	29	.000
	Pair 4	dPost - dPre	.900	.712	.130	.634	1.166	6.924	29	.000