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Interactive BIM-enabled Safety Training Piloted in Construction Education

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ABSTRACT

This paper documents and assesses the development of a construction safety training module featuring interactive, BIM-enabled, 3D visualizations to test if such a tool can enhance safety training related to scaffolds. This research documents the technical challenges and the lessons learned through the development and administration of a prototype training module in a required undergraduate construction safety course at Colorado State University. Student feedback was strongly positive, and findings suggest that such an innovative teaching method may be more effective than traditional teaching methods based on pre and post knowledge-testing. Such research highlights future opportunities to develop more extensive and advanced training modules using interactive, BIM-enabled, 3D visualization techniques in support of safety training within construction education.

Key Words: Construction Education, Safety Training, Interactive Learning

INTRODUCTION

Opportunities exist to improve construction safety training. In 2012, there were 775 fatalities in the private construction sector (BLS, 2013). A comparison of fatality rates regularly ranks the construction industry among the three most dangerous in the United States (Abudayyeh, Fredericks, Butt, & Shaar, 2006), and in 2012 construction had the highest number of fatalities when compared to any other industry sector (BLS, 2013). Furthermore, fatal and non-fatal injuries and illness rates in construction maintain high levels despite focused attention by the industry on safety procedures and programs (Abudayyeh, et al., 2006). Such data suggests that there is a lack of successful communication regarding safety procedures, hazard identification and site-specific conditions on construction sites. Of particular concern to industry are workers who have limited worksite experience, such as interns and recent construction management graduates, who are more likely to get injured on the worksite than workers with more experience. (OSHA Young Workers, n.d.).

Researchers have begun to investigate opportunities to integrate Building Information Modeling (BIM) into construction education. According to a survey of 101 Architecture, Engineering and Construction (AEC) programs in the United States in 2009, Becerik-Gerber, B., Gerber, D.J., & Ku, K. (2011) found that 60% of the construction programs, 56% of architecture programs, and 38% of the engineering programs have infused BIM concepts into traditional courses and design projects. Specifically, BIM provides the opportunity to virtually demonstrate concepts to students using familiar 3D visualizations, and preliminary research has shown that visualization may enhance the students' ability to conceptualize and understand construction concepts (Clevenger, Glick, and Lopez del Puerto, 2012).

BIM technologies are being used in a variety of areas to assist in issues related to construction health and safety including: (1) Design for safety; (2) Safety planning (3) Safety training; (4) Accident investigation; and (5) Facility and maintenance phase safety (Rajendran and Clarke, 2011). In addition, Lucas and Thabet (2008) suggest that interactive (CAD-based) training offers a chance to teach real life events in a virtual environment with an effect of reducing injuries and fatalities. Recently, researchers have begun to investigate the use of BIM to enhance construction safety planning and management (Zhou, Irizarry, and Li, 2013; Azhar, Behringer, Sattineni, and Mqsood, 2012; Rajendran and Clarke, 2011), as well as the use of BIM to increase communication within the context of construction safety training (Park and Kim, 2013; Azhar and Behringer, 2012; Chi, Hampson, and Biggs, 2012). Previous research demonstrated computer-based safety work-force training is most effective for both older and younger workers when they are shown a combination of text with pictures and audio narration to ensure the visual and verbal information is combined in the working memory (Wallen, and Mulloy, 2006). Currently, researchers are also beginning to investigate the use of BIM in support bi-lingual safety training (Clevenger, Lopez del Puerto, Glick, 2014; Azhar and Behringer, 2012). In general, however, more research is needed that focuses primarily on the role of visualization in safety training (Han, Peña-Mora, Golparvar-Fard and Rho, 2009) and its potential role in undergraduate construction safety education.

PURPOSE OF THE RESEARCH

A critical need exists to improve safety training for construction management students and working professionals. To this end, the use of classroom exercises provides a valuable test bed to investigate new safety training and teaching techniques that may be applicable to industry safety training programs. This research develops a prototype interactive, BIM-enabled, safety training module to test the innovative platform's use in the classroom. Future research will document learning outcomes of expanded training modules and may include actual construction workers participants. The goal of this research is to test if interactive, BIM-enabled training modules effectively enhance communication regarding safety procedures, hazard identification and site-specific conditions with the intent to improve student learning and the ultimate goal to reduce the number of injuries and fatalities on construction worksites in the future. The authors elected to create a module focused on scaffold safety specifically because falls are the number one cause of fatalities in construction (OSHA, n.d.).

METHODOLOGY

A mixed methods research design was used for this study and is appropriate where qualitative and quantitative data are collected concurrently (Creswell, 2009). The initial research tasks was to develop a BIM enabled teaching module. The two part training module was specifically developed to meet OSHA requirements for scaffolds as stated in 1926 subpart L – Scaffolds. Subpart L addresses specific scaffold requirements regarding platform width, plank spacing, guardrails, access points, etc. that must be followed to comply with the regulation (OSHA, n.d.). The training module administration and data collection followed a pre-test, intervention, post-test model. Results of the two knowledge tests were used to measure the potential impact of the BIM-enabled safety training module. Once the students completed the overall process they were asked to respond to a survey to share problems and provide feedback on the process. Demographic information was collected at the time of the post-survey (Figure 1).

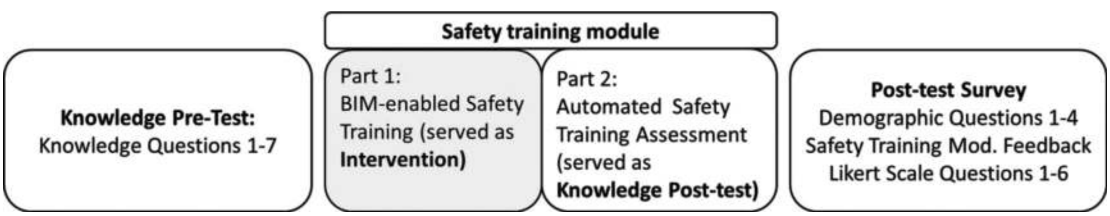

Figure 1. Safety Training Module Intervention Sequence.

Training module administration consisted of pilot testing the module in spring 2013. Students enrolled in the fall 2013 construction safety management course at Colorado State University were asked to complete a pre-test (Figure 1). The pre-test consisted of seven (7) knowledge-based questions. The students were then assigned the BIM-enabled safety training module as homework which they completed using their online version of the Blackboard system. Using the module, the students completed a computer-based post-test, which asked the same 7 knowledge based questions as the pre-test. Finally, students completed a paper-based survey during the class period following the homework assignment which solicited their opinions regarding the impact of the teaching module using six (6) Likert-scale questions (5 highly agree, 1 highly disagree). They were also asked an open-ended question soliciting general feedback on the module. In addition, they were asked four (4) multiple-choice demographic questions, and one open-ended question regarding preferred methods of data presentation. The demographic questions pertained to participants' college major, undergraduate year equivalent (freshman, sophomore etc.), experience working with scaffolds and amount of previous scaffold training.

No incentives were given to the students and the assignment had no impact on students' grades in the class. The assessment protocol for the survey questions was submitted and approved by the university Human Research Board (IRB/HRB).

DESCRIPTION OF BIM-ENABLED SAFETY TEACHING MODULE

For this research, the authors developed a two part training module consisting of interactive training and computer-based assessment. This module was produced in two versions: one in English (subtitles and narration) available at: http://learning.colostate.edu/courses/bim/safety/english/SafetyTraining.htm, and one in Spanish (subtitles and narration) available at: http://learning.colostate.edu/courses/bim/safety/spanish/SafetyTraining.htm, which is further documented in Clevenger et al. (2014). Only the English version was administered to the construction students and is the focus of this research.

The authors elected to create the BIM-enabled safety training module using Adobe® Captivate® 6 software (Adobe, 2013). Captivate is a e-Learning content development software capable of integrating visualizations and animations, text and audio clips into interactive simulations, branching scenarios, and quizzes outside of the original, native software(s) platform. To create the BIM-enabled safety training module, the authors first created visualizations and animations in native 3D modeling Revit software to illustrate the safety training concepts.

Part one, the interactive training section, used the following activity types to engage the trainee and demonstrate safety concepts: drag and drop selection, video animations (fly-around), and user guided placement (e.g.; placing a mid-rail or arranging plank overlap etc.). Figure 2 illustrates the

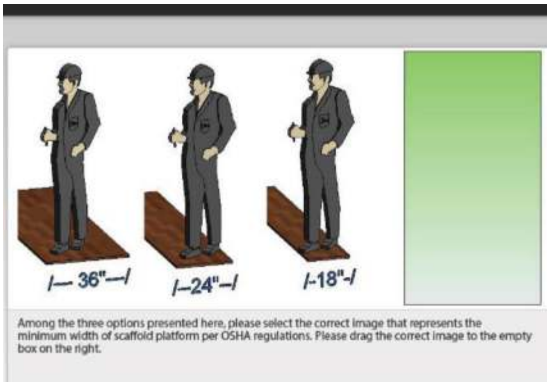

Figure 2. Interactive training, drag-and-drop.

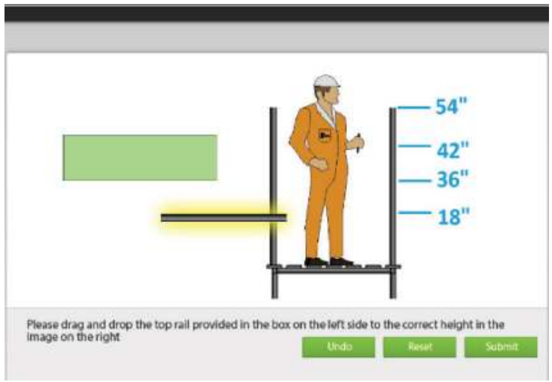

Figure 3. Interactive training, user-guided placement.

use of an interactive drag and drop selection activity to demonstrate minimum plank width to the trainee. Figure 3 illustrates the use of interactive user guided placement activity to demonstrate proper mid-rail height to the trainee.

Part one concludes with an illustration of how to place the scaffolding on a specific construction site. Figure 4 is a screen capture of the animated fly-through populated with distinguishing landmarks of a representative construction site.

Although the illustrations created in Revit for the training module are relatively simple, they demonstrate a strong proof of concept that more complex or site-specific 3D safety illustrations can be generated using native software widely used by the construction industry to model building

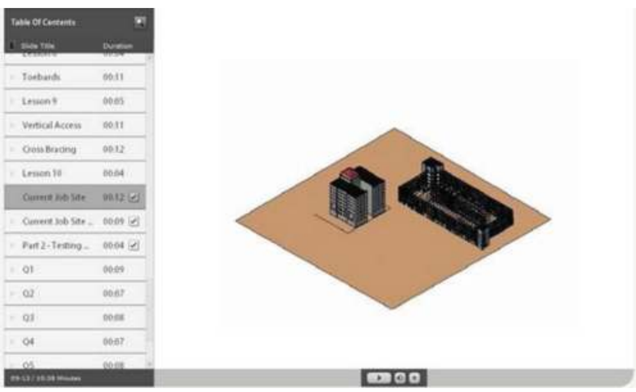

Figure 4. BIM-enabled visualization of a construction site used in teaching module.

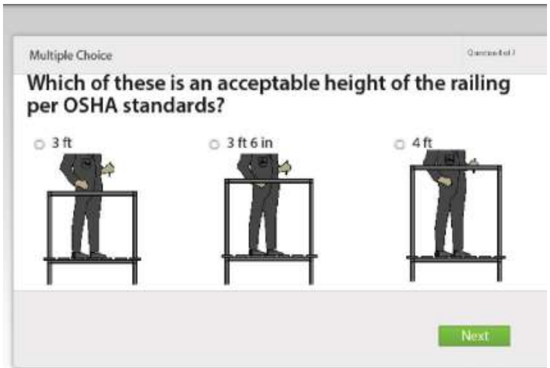

Figure 5. Assessment question regarding scaffolding plank overlap.

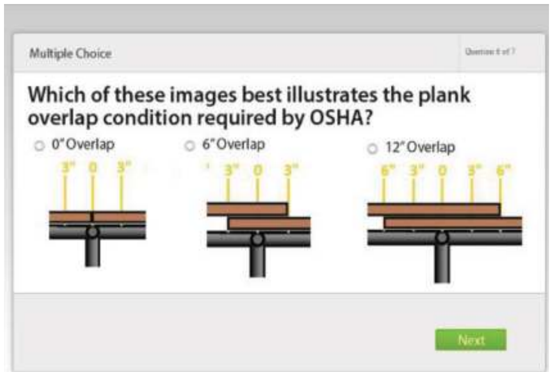

Figure 6. Assessment question regarding scaffolding plank overlap.

projects and sites. The site model used to develop the training module (as shown in Figure 4) was provided by a leading, professional construction management firm, and confirms the existence and compatibility of such models to be used to develop custom, site-specific, virtual safety training for construction students and workers in the future.

Part two of the training module consists of seven knowledge-based multiple choice questions that assess if students can correctly identify and apply safety concepts related to the scaffolding as conveyed during part one of the training module. Figure 5 illustrates an assessment question where the student identifies the proper placement height of the scaffolding mid-rail. Figure 6 illustrates an assessment question where the student identifies correct plank overlap. All seven assessment questions were presented interactively, on-line and individual results were recorded electronically.

After part one and part two content was developed using Adobe Captivate to integrate the Revit-generated illustrations, videos, text and audio narration, the safety training module was published to an html file. The resulting product is a stand-alone, software independent, executable file that can be viewed using an Abode flash player or an internet browser. Using such a platform, individual assessment scores can be recorded directly through a web-based learning environment such as Blackboard.

DEVELOPMENT CHALLENGES

Several technical challenges were quickly revealed during the development and pilot testing of the safety training module, several which may be indicative to development of virtual or e-learning environments in general. First was the challenge of creating a fully "tested," on-line training module. During student pilot implementations of the teaching module errors or bugs appeared that the authors had not witnessed during development or testing of the training module despite having viewed the module using a variety of computer systems. These included 1) problems restarting, advancing or rewinding the module, 2) problems viewing the videos or asynchronous narration with slow video and 3) problems recording assessment results. Such issues were mainly the result of either different software or hardware specifications, slow internet speed, and/or impatient, inconsistent users. Specifically, when training modules were implemented by students on-line, they viewed and interacted with the e-learning environment using both windows and mac operating systems as well as using numerous (and numerous versions of) browsers. Such differences led to minor yet, at times, problematic changes in screen layout sizing etc. Students are also notoriously demanding on software and frequently double-click, reverse, restart, or repeat optional entries, in an unforeseen manner, which can be problematic if untested.

Another issue, although reportedly only a temporary upgrade issue, was that the author's university's Blackboard digital learning platform was not compatible with robust collection of either individual or group assessment results and such data had to be collected in individual electronic files. Despite of these issues, the safety training modules were generally well received by the students in the classroom.

STUDENT PARTICIPANT DEMOGRAPHICS

In fall 2013, 50 undergraduate students enrolled in the Construction Safety course offered through the Department of Construction Management at Colorado State University. Out of the 50 students enrolled in the course 43 students completed the survey (86% response rate). Table 1 provides a summary of participant demographics.

KNOWLEDGE TESTING RESULTS

The seven pre-test knowledge-based questions and training module assessment questions (post-test) were identically worded. The pre-test was paper-based and the teaching module assessment consisted of interactive, graphic computer-based questions. The difference in delivery format for the pre- and post- tests was due primarily to classroom logistics. The pre-test was delivered during class (in a classroom without computers), and the post-test was delivered on-line as part of the training module. Table 2 presents knowledge-testing results based on student recorded responses to the pre-test and teaching module assessment (post-test).

Major	N	%
Construction Management	40	93%
Other	3	7%
Year in School	**N**	**%**
Sophomores	18	42%
Juniors	19	44%
Seniors	6	14%
Experience working on or around scaffolds	**N**	**%**
No experience	11	26%
Less than 3 months	11	26%
Between 3 months and one year	10	23%
More than one year	11	26%
Hours of safety training on scaffolds (in the last 5 years)	**N**	**%**
No training	30	70%
One hour	5	12%
2 hours	4	9%
3 hours	2	5%
4 hours	0	0%
5 hours or more	2	5%

Table 1. Students Participant Demographics.

Table 2 demonstrates the differences in student performance pre- and post-intervention. Ideally, to fully assess the impact of the training module on student learning, the authors would compare students' performance results to those of a control group, where traditional teaching methods were administered. Unfortunately, due to limitations in class logistics, this was not possible. However, it should be noted from student post-test survey data, while 70% of the students had had no prior training related to scaffolding, 30% had received somewhere between 1-5 hours of related professional, on-site scaffold training.

STUDENT FEEDBACK

After completing the interactive safety training module, students were given a paper-based feedback survey in class soliciting opinions regarding the impact of the module using six (6) Likert-scale questions (5 highly agree, 1 highly disagree). Table 3 shows the results of student responses to these questions. In general, post-survey results were very positive. 82% of participants either

#	Question	Possible Responses	OSHA Regulation	Percent of students answering the question correctly: Pre-Test	Post Test
1	Minimum width of a scaffold per OSHA regulations	a) 36” b) 24” c) 18”	18 inches (46 cm) wide	5%	98%
2	The best option for an exterior scaffold per OSHA regulations	a) with base plate b) without a base plate c) with wheels	Shall bear on base plates and mud sills or other adequate firm foundation	98%	100%
3	Maximum allowed space between planks per OSHA regulations	a) 2” b) 1” c) 3”	No more than 1 inch (2.5 cm) wide…	33%	98%
4	Required height of top rails per OSHA regulations	a) 3 feet b) 3 feet 6 inches c) 4 feet	Shall be 42 inches (1.1 m) plus or minus 3 inches (8 cm) above the walking/working level…	53%	98%
5	Required height at mid rails per OSHA regulations	a) closer to the platform b) exactly at midpoint c) closer to the top rail	Midway between the top edge of the guardrail system and the walking/working level	60%	98%
6	Correct plank overlap per OSHA regulations	a) 0” b) 6” overlap c) 12” overlap	Shall not be less than 12 inches (30 cm)	33%	88%
7	Best vertical access per OSHA regulations	a) at ladders or stairs b) midpoint of scaffolds c) at cross braces	At ladders or stairs. Cross-braces shall not be used as a means of access	56%	100%

Table 2. Testing Results.

agreed or highly agreed that they liked to see the computer model. 65% either agreed or highly agreed that they would like to see more computer models in their safety training. 77% either agreed or highly agreed that interacting with the computer simulation model increased their understanding and knowledge about scaffolds. 89% either agreed or highly agreed that interacting with the computer simulation model increased their understanding and knowledge about OSHA regulations regarding scaffolds. 65% either agreed or highly agreed that interacting with the computer simulation model increased their understanding of scaffold assembly and 74% either agreed or highly agreed that interacting with the computer simulation model increased their understanding of proper use of scaffolds.

Construction Management Students	Highly Agree (5)	Agree (4)	Neither Agree or Disagree (3)	Disagree (2)	Highly Disagree (1)	Mean
I liked seeing the computer model						
Number of Students	8	27	4	1	3	3.84
Percentage	19%	63%	9%	2%	7%	
I would like to see more computer models in my safety training						
Number of Students	10	18	11	1	3	3.72
Percentage	23%	42%	26%	2%	7%	
Interacting with the computer simulation model increased my understanding and knowledge about scaffolds						
Number of Students	8	25	7	3	0	3.88
Percentage	19%	58%	16%	7%	0%	
Interacting with the computer simulation model increased my understanding and knowledge about OSHA regulations regarding scaffolds						
Number of Students	11	27	4	0	1	4.09
Percentage	26%	63%	9%	0%	2%	
Interacting with the computer simulation model increased my understanding of scaffold assembly						
Number of Students	7	21	9	5	1	3.65
Percentage	16%	49%	21%	12%	2%	
Interacting with the computer simulation model increased my understanding of proper use of scaffolds						
Number of Students	7	25	8	2	1	3.81
Percentage	16%	58%	19%	5%	2%	

Table 3. Student opinion regarding the impact of safety training module.

Table 4 presents students stated preferences regarding style of the delivery / presentation of the information.

On the following page is a summary of representative responses to the open-ended question soliciting student feedback on the teaching module.

	Text	Pictures of other projects	Generic Drawings	Generic Computer Models
1= Most Effective	7	13	7	9
2	7	13	12	9
3	9	9	16	8
4 = Least Effective	17	5	5	14

Table 4. Student Preference regarding style of information presentation.

Student Comments:

- "Picture and demonstrations helped me understand the material. I liked the quiz and questions afterwards to make sure I learned the material."
- "Interactive assignments like this would be good reinforcement of homework's."
- "There were a few confusing parts, but overall I thought the simulation model was an excellent learning exercise."
- "I found this exercise beneficial. It should be implemented in future classes to teach students. The interactive 3D model is a great way to learn and preferred over traditional methods."

ADDITIONAL THOUGHTS AND OBSERVATIONS

A significant opportunity exists for construction safety training to utilize BIM-enabled visualization to provide a robust, interactive, site-specific educational experience for construction students and workers. However, the implementation of the safety training module by construction students highlighted the following issues as worthy of future research.

- In the future, held-hand or phone apps may present student-friendly and even construction worker-friendly platforms for interactive safety training and / or on-line training "libraries." Equipment manufacturers, industry, and academics should work together to provide readily accessible safety data and animations that can be placed in BIM models and/or accessed through quick response (QR), 2D bar codes directly on-site. Educators could be instrumental and inform such efforts by continuing to develop interactive student activities, and using students to pilot test various training techniques.
- A significant benefit to computer-based interactive teaching modules, particularly for critically important topics such as safety education, is the ability to provide real-time student assessment. Using custom on-line safety training modules with built-in assessment capabilities may prove invaluable for confirming and testing the impact of teaching and the effectiveness of communication, especially for non-native language speakers. As with any educational material, however, it may be necessary to safeguard against "answer sharing" for on-line applications.
- Computer-based training techniques involving 3D visualization, should only be one of multiple educational techniques used to support safety training in order to accommodate a variety of different learning styles. Such a recommendation was confirmed in student responses to an open-ended question in the post-survey where they were asked to rank their preference for information presentation: text, pictures of other projects, generic drawings or generic computers models. Three (3) students out of the 43 students that participated in this study did

not respond to this question. In general, however, preference varied significantly (see Table 4), highlighting the need for multiple presentation styles.

CONCLUSION

This research developed an interactive, BIM-enabled safety teaching module (available at: http://learning.colostate.edu/courses/bim/safety/english/SafetyTraining.htm), and administered it to 50 undergraduate students enrolled in construction safety management class at Colorado State University. Pre and post knowledge-testing was performed. Results suggest that completion of the teaching module is effective and correlates to a higher level of knowledge compared to only using the standard, more traditional, training techniques. Specifically, the average score for student responses to the seven knowledge-based OSHA requirements test questions on the paper-based pre-test was 48% which increased to an average of 95% after completing the interactive safety teaching module. While it was not possible to compare student scores to those of a control group's, anecdotally the instructor, who taught similar information to students at the same institution using traditional techniques for five years prior, observed that student performance and interest level noticeably improved. Further support of this estimation was provided through informal discussions with the students. Furthermore, student qualitative and quantitative feedback on the safety training module was strongly positive. Finally, several valuable lessons learned were generated regarding the use of BIM-enable interactive learning which may inform safety training, construction education and beyond.

Future research is needed using more advanced and expanded training modules related to construction safety and other important content areas in construction. In particular, studies need to be performed to test the duration of knowledge persistence after various training techniques are completed. One limitation of the current research is the administration of the knowledge assessment immediately following the training. Additional research is needed to test if various teaching techniques are more effective over a longer period of time and how the persistence of knowledge may correlate to teaching and learning styles.

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