Leveraging Immersion Technologies in Construction Management Education: A National Electrical Code 3D Simulation Tool

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Universities across the country are moving to outcome-based learning as a means of evaluating educational programs. The change from a prescriptive to performance-based curriculum is due, in part, to the change in the attitude and learning style of the millennial student. To meet the needs of millennial students, Clemson University has developed an interactive, 3D computer simulation (Simulation) to teach the National Electrical Code (NFPA70). The Simulation recreates a virtual construction site where 14 potential code violations are present. The Simulation provides a "help option" where student are provided a hint to guide them to the relevant code section. The help option was included so that the simulation could be used as a teaching tool and not just to assess their understanding of the NEC. This paper elaborates on 14 code violations programmed into the Simulation and the justification as to why those were specifically selected. In addition, four sample violations are elaborated on in greater detail to clarify to the reader what the software specifically does. This paper will also summarize a pilot study conducted using the Simulation and the positive student feedback received on its inclusion in an environmental systems course.

Key Words: Computer Simulation, Electrical Code, NFPA70, Active Learning, Construction Education

Introduction

Universities across the country are moving to outcome-based learning as a means of evaluating educational programs. The change from a prescriptive to performance-based curriculum is due, in part, to the change in the attitude and learning style of the millennial student. In modern university education, lack of access to information is no longer a barrier to learning. Using the information with "active learning" exercises provides the best educational experience for millennial students (Lee, 2011; Roehl, Reddy, & Shannon, 2013; Walvoord & Anderson, 2010; Wilson & Gerber, 2008). Active learning can occur through a number of class activities such as class projects, case-based teaching, peer-to-peer learning and educational games (Deslauriers, Schelew, & Wieman, 2011; Kember & McNaught, 2007). No matter what specific activity is used, millennial students value student-centered learning, interactive environments, rapid feedback, and engaging learning activities (Kember & McNaught, 2007; Kamardeen, 2014). The construction science and management program at Clemson University is incorporating 3D virtual reality simulations in its curriculum to increase the engagement and learning retention of students. This paper describes a pilot study using computer simulation to teach the 2014 National Electrical Code (NFPA70) as part of an environmental systems course. This paper will elaborate on the specific code violations simulated, how the simulation was used with the students and the students' perception of the software as a learning tool.

Cognitive Learning and the Use of 3D Simulations

Many educational programs are taking advantage of 3D simulations because they believe that this tool improves cognitive learning (Lucas & Thabet, 2008). "Cognitive learning" is learning through individual experiences and reasoning. One model of cognitive learning is the improved interaction between students' working memory and their long-term memory. Working memory is accessible only for a short time (Baddeley & Hitch, 1974). What a person had for breakfast will be stored in the working memory. That memory may be accessed by a person later in the day but, likely, not later in the week. Long-term memory is where information is retained for long periods (Shiffrin & Atkinson, 1969). The transference from working memory to long-term memory is referred to as "encoding" (Lucas & Thabet, 2008). Skill sets are developed when the working memory is successfully encoded to long-term memory and then applied in a real-world context (Clark & Mayer, 2003). With this model of cognitive learning, 3D simulations work well because they require the students to experience their new environment through multiple senses and use cognitive reasoning to solve problems. This combination of experience-based information gathering and individual reasoning is at the core of cognitive learning and much more effective at encoding working memories for long-term skill set retrieval.

Benefits of 3D Simulation in Construction Management Education

Gier and Hurd observed that construction management students "are kinesthetic learners and prefer to learn by doing" (2004). Field trips, lab exercises, and mock-ups are excellent ways to appeal to construction management students. However, field trips and lab exercises can be difficult to coordinate with large groups, and mock-ups can be expensive to build, store, and update. There has been a great deal of success teaching using computer simulations (Kapp, 2013). The use of 3D simulation has several important advantages to traditional approaches in construction management education. Logistically, 3D simulations are easy to store, update, and build upon. Simulation software can be loaded on a student's computer so that it can be used in class and avoid the need for a computer lab. Built-in instruction can be used for learning activities outside the classroom. Perhaps the biggest advantage of using 3D simulation is that it aligns well with what millennial students' value most in their education. Kember & McNaught identified what students' value most were student-centered learning, interactive environments, rapid feedback, and engaging learning activities (2007). 3D simulations are student-centered by design. Students can navigate the virtual environment, think through the problem, collect the required information, and then propose a solution. 3D simulation can be especially interactive and reinforce cause-and-effect relationships in construction. As students make decisions they receive instant feedback, and the environment changes to reflect their choices. 3D simulations also are highly engaging for students; it is easy for them to make the connection from the lesson to a practical benefit.

NEC Simulation

The NEC is taught in an environmental systems course at Clemson University. To improve the engagement and retention of the material, a 3D computer simulation (Simulation) was created by the department with the help of a local software development firm. The Simulation immerses the student into the virtual environment of a commercial building under construction. The intention of the Simulation is to create a virtual environment that the students can interact with and through the interaction have a better understanding of the NEC. The Simulation is less than 200MB and easily stored on a USB flash drive. When the student opens the program a main menu is loaded where the user can get instructions on how to use the software and information on the sponsors (figure 1).

Figure 1: Simulation main menu

When students select the "Start" option from the main menu they are "virtually" standing in the main lobby of an ongoing construction project. From this point the student is free to move about the Simulation similar to a first-person-shooter type video game. This provides the student a sense of self direction and control of their own learning. To help guide the student through the Simulation, green arrows on the floor direct them to the potential code violations (figure 2). The approach allows the student to proceed at their own pace, but still provide enough direction so they meet the learning objectives of the program.

Figure 2: Simulation starting point

The Simulation is programed with 14 potential NEC violations. The green arrows directs the students to various rooms where spinning green numbers hover over potential violations. When the student approaches the spinning green number a question appears. For example, the first potential NEC violation is located in the main electrical room. In the main electrical room a section of HVAC ductwork is hung above an electrical switchboard. As the student approaches the potential NEC violation a textbox appears where the student is asked "Is the metal duct a violation of the required dedicated space for the switchboard?" (figure 3 left). By navigating the simulation and reading labels on the equipment the student can see that the ductwork is 3' above the switchboard and that the switchboard is sized for 277/480, 3phase, 800amp power (figure 3 left). Article 110.26 (E) of the NEC indicates that no ductwork can be located in the space 6' above the foot print of the equipment. Because the ductwork is only 3' above the equipment this is a violation of the NEC. However, if the student is unable to find the correct NEC article a "hint" option is available which highlights the important information found in the room and the applicable NEC article. The student receives a 20% penalty per question if the hint option is used. This provides a strong motivation to try the question on their own but gives a lifeline if they need one. After the student chooses their answer the correct response is provided along with an explanation of why it is or isn't a violation (figure 3 right). In addition, the code violation is mitigated. In this case, the ductwork is raised to 6' above the equipment and the dedicated space is shown as an orange box (figure 3 right).

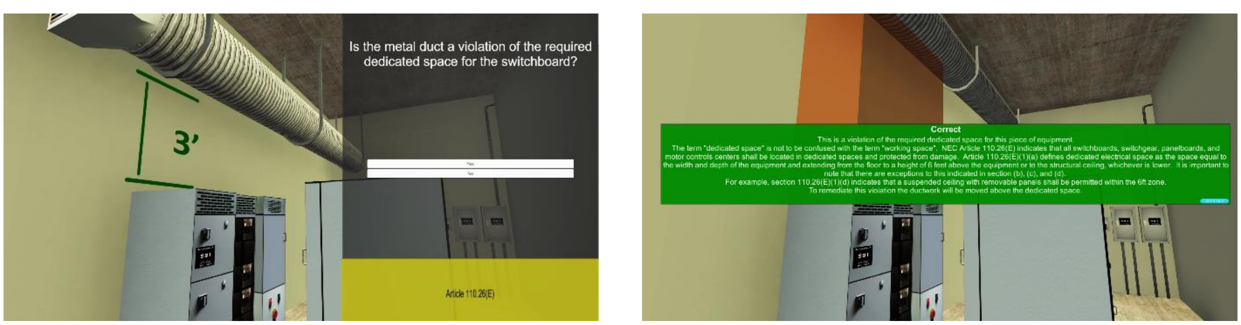

Figure 3: Code Violation #1: Ductwork in dedicated space

Fourteen NEC Violations

When developing the NEC curriculum considerable thought went into determining what depth it should be covered as to not take away time from other important electrical topics. The determination made was that students should have enough exposure that they could participate in a jobsite electrical code discussion and feel comfortable using the NEC to look up specific information. Additional efforts were made to determine which specific violations were appropriate for this level of understanding of the NEC and the students' likely role in the construction industry. The violations selected aligned around three key tasks where it was felt that the students would most use the NEC. These areas are preconstruction services, field quality control, and change order management. Specific recommendations on code violations were solicited from general contractors, construction managers, electrical contractors, electrical engineers, and code officials to help identify which violations would best facilitate these three tasks. A list of the potential code violations included with the Simulation can be found in table 1. Although the violations are grouped by task, there is a great deal of overlap between them.

Table 1

Simulation Potential Code Violations

CM Task	Code Violation No.	Description
Preconstruction Services	CV1	Dedicated Space Violation – Duct/Switchgear Conflict
	CV2	Working Space – Switchgear/Switchgear Proximity
	CV3	Working Space – Switchgear/Wall Proximity
	CV4	Number of Paths of Egress – High Voltage Switchgear
	CV5	Working Space – Panels/Wall Conflict
	CV6	Working Space – Panels/Panel Conflict
Field Quality Control	CV7	Switch Mounting Height
	CV8	Maximum Wire Ampacity
	CV9	Excessive Voltage Drop
	CV10	Disconnect Location
	CV11	Maximum Number of Bends in Conduit
Change Order Management	CV12	Conduit Support Distance
	CV13	Maximum Number of Conductors in a Conduit
	CV14	Maximum Number of Conductors in a Junction Box

Code Violation 2 – Working Space

There is insufficient length in this conference proceeding paper to elaborate on each of the 14 violations included with the Simulation; however, this paper will review three additional violations and show how they provide value in preconstruction services, field quality control, or change order management. Code violation #2 addresses working clearances. To prevent electrical arcing and to provide safe access to the equipment, the NEC requires minimum clearances around equipment referred to in the code as "working space." The depth of the working space is dictated by the voltage of the equipment and how conductive the surrounding surfaces are. Lower voltage equipment surround by insulated walls do not have the same working space requirements as higher voltage equipment adjacent to other equipment. In code violation #2, two 277/480V switchboards are facing each and are 3' apart (figure 4 left). Students are tested on their knowledge of working space by asking if the provided 3' is sufficient. The voltage of the equipment is the critical parts of this question but this information is not provided in the question itself. The student needs to read the equipment label and know the appropriate code to answer this question. NEC article 126(A)(1) indicates that in this situation, 4' of clearance is required. In this case only 3' is provided so this is a violation of the NEC. In figure 4 (right), the student answered the questions incorrectly. The text box, shown in red for an incorrect response, provides a narrative to where the requirement can be found in the NEC. Knowing the required working space of equipment is very important in preconstruction. Owners prefer to minimize mechanical and electrical spaces and may not know the larger impacts of changing voltages of equipment. Students who will work in preconstruction should have a working knowledge of the required working space so they can help owners layout their utility rooms and maximize the usable space.

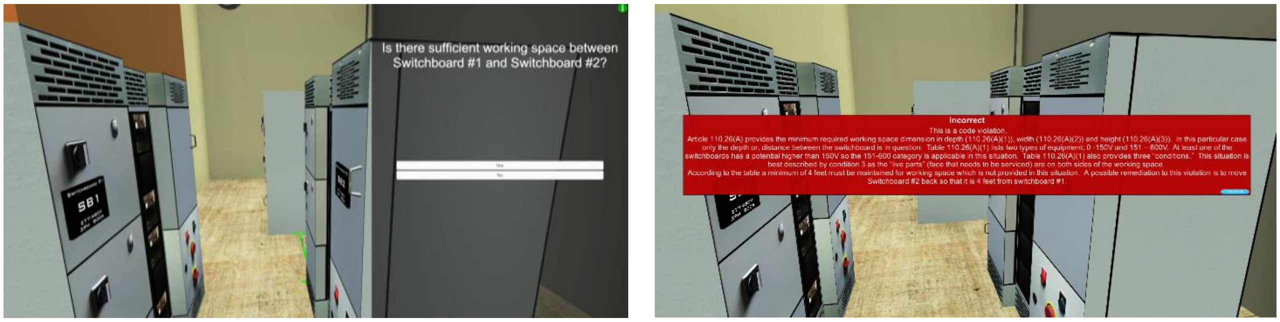

Figure 4: Working space example

Code Violation 11 – Maximum Number of Bends in Conduit

An important quality control component in electrical installation is straight conduit. Aside from the underappreciated aesthetic appeal to a bank of perfectly run conduits, unnecessary bends in conduits add labor cost. The NEC limits the number of bends in conduit for safety reasons. Excessive bends in a conduit makes it harder to pull conductors through it. When conductors are pulled with excessive resistance they may stretch, reducing the diameter of the conductor and its ampacity. Conductors with reduced ampacity will heat up more and increase the chance of fires. In code violation #11, the students are exposed to a situation where the electrical contractor has a circuit for a wall mount television (figure 5). The students are then told that the length of the EMT conduit run is 65' and asked if a pull box is required. The length of the run is irrelevant. What is important for this question is the number of bends in the conduit. The students must find that there are five, 90 degree bends in the run. The five bends are show with blue circles in figure 5 to demonstrate their location in this paper. The blue circles are not provided to the student in the simulation. NEC article 358.26 indicates that there shall not be more than the equivalent of four quarter bends. This is commonly called the 360 degree rule. In this case, the contractor would have to either add a pull box or rerun the conduit to eliminate some of the bends. In the remediation of this code violation the conduit is rerun so the conduit enters the panel board from the top eliminating the two bends below.

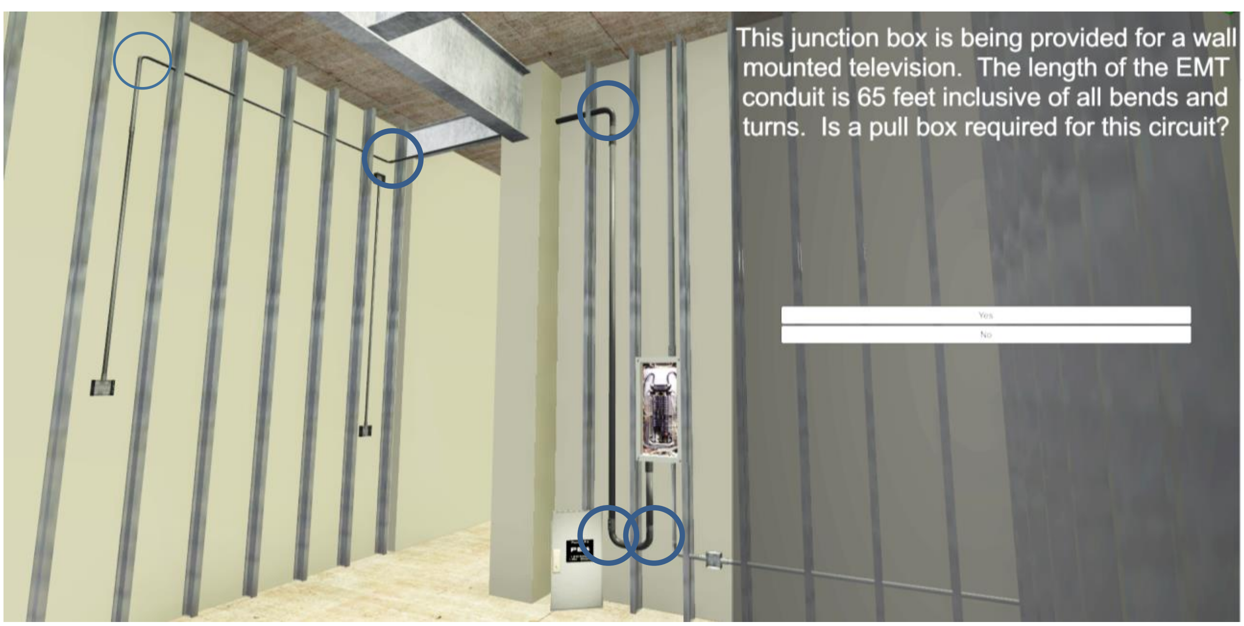

Figure 5: Maximum number of conduit bends example

Code Violation 12 – Conduit Support Distance

Code violation #12 simulates a potential change order management issue. The potential code violation provides a scenario based question where a change order is being performed on a time and material basis. The young superintendent is challenging why it is taking the electrical contractor so long to complete the change order. The superintendent notices that the EMT conduit is being supported every 3'. When she addresses this with the electrical foreman he indicates generically that the NEC requires them to install it this way. The code violation question then asks if the electrical foreman is correct (figure 6 left). In this situation, the electrical contractor misinterpreted the code. The conduit does need to be supported 3' from the point of conduit termination but is supported every 10' in open runs. The more cost effective installation of the conduit is shown in figure 6 (right).

Figure 6: Conduit support distance example

Pilot Study

The Simulation was developed as part of a pilot study to determine if computer simulation can enhance not only the instruction of the NEC but other construction management courses as well. The effectiveness of the Simulation was assessed through student survey and quantitative results from NEC assessments. For this experiment, two sections (control; n = 16 and experimental; n = 20) of the same environmental systems course was used. The NEC material was taught over three 75-minute class periods. The first class period was the same for both sections and consisted of a lecture covering the organization of the NEC, a mock-up to demonstrate various violations, and a short in-class assignment. The second class period for both sections was used for an in-class quiz on the NEC. The experimental section used the Simulation while the control section used 2D sketches and narratives. The sketches and narratives are the same documents used to describe the violations to the computer programmers who developed the Simulation. The students in the control section wrote their answers on paper and turned their responses into the instructor at the end of the period. Each section had 60 minutes to address all 14 NEC violations. In the third class period, the instructor went through each of the code violations with the students. In the experimental section the instructor had the Simulation on an overhead projector and went through each violation one by one. The specific information needed to answer the questions and where the information could be found in the Simulation was covered in detail. The students had the Simulation running on their laptops so they could follow along with the instructor. The control section had a similar exercise only they used 2D sketches and narratives instead of the Simulation. At the end of the third day of the experiment the instructor distributed a student satisfaction survey that addressed their level of engagement, satisfaction with the simulation and where other similar simulations could benefit their curriculum the most.

Student Satisfaction Survey Results

The students in the experimental section where asked about their experiences using the 1 – 7 Likert scale survey where 1 was low and 7 was high. Three specific questions, shown in table 2, indicate that the students viewed the Simulation favorably. The first question from Table 2 asked the students directly if the simulation "…improved your learning experience…" The students rated the Simulation at 5.2 out of 7. Of the 20 students surveyed only 3 students rated it as dissatisfactory. Of these three students, one commented that they liked the Simulation, just not for quizzes. Another commented that they just had no interest in the NEC and the third had technical issues and the Simulation ran very slowly on their computer. Table 2 also shows the responses from the students when asked if "…computer simulation should be used to teach the NEC in the future?" The feedback was also largely favorable with a 5.9 out of 7 response. The students were also asked if other courses could benefit from other similar 3D simulations. The response to this question was also high. Table 2 shows that the students' interest was rated 5.8 out of 7 for more simulations in other CM courses. The two courses they indicated would have the most value were material & methods and estimating. The structures course was also mentioned by several students as a good class to use 3D simulation. The purpose of this paper is primarily to demonstrate the software so that it can be taken back to other universities and incorporated into their curriculum. The pilot study is references here only to support that it will likely be well received by other students. A comprehensive evaluation of the pilot study and the survey findings are the subject of another paper published in the 2015 International Conferences on Construction Applications of Virtual Reality (Burgett, 2015). .

Table 2

Student Survey Results

Survey Questions (Rated 1-7)	Experimental	Std Dev
Did the use of 3D computer simulation improve your learning experience of the NEC or distract from it?	5.2	1.5
How strongly to do feel that the use of 3D computer simulation should be used to teach the NEC in the future?	5.9	1.3
How high is your interest in 3D computer simulation in other CSM classes?	5.8	1.3

Conclusion

Millennial students learn much differently than past generations. Access to information is no longer a barrier to learning. The use of the information through active learning exercises with immediate feedback is highly desired by the current generation of university students. This paper describes a 3D computer simulation to teach the NEC to construction science and management students. Fourteen potential electrical code violations are embedded into a computer simulation. Students are required to use the conditions of the virtual environment, along with the understanding of the NEC, to determine if violations are present. A satisfaction survey showed that the simulation was well received by the students. Courses the students felt that similar simulation programs could benefit from were material and methods and estimating. The structures courses were also mentioned as classes that would benefit from computer simulation. The primary purpose of this paper was to demonstrate the new simulation tool and make it available to other universities. Construction management programs interested in incorporating the simulation into their curriculum are encouraged to contact the author of this paper.

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