Designing Educational Virtual Environments for Construction Safety: A Case Study in Contextualizing Incident Reports and Engaging Learners

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Abstract. Safety education is important in the construction industry, with many onsite injuries and fatalities. Reviewing incident reports can be valuable in preventing the same mistakes from reoccurring and in reinforcing the concept of designing for construction safety. However, the required information can be difficult for students and non-experts to understand in a meaningful way without instructor facilitation. Recently research has shifted into using 3D virtual environments for safety education, with applications teaching learners how to identify hazards and operating procedures. While there are exploratory results on student engagement and overall learning, there is less focus on how the design influences the learning outcomes. For these reasons we conducted a case study in system design to understand how to effectively contextualize raw incident reports into a meaningful 3D educational experience. From our case study, we present a single-learner educational application with both a desktop computer and VR version. The desktop version was used in development of the applications design framework and in a controlled study testing how interaction techniques influence learning and behavioral outcomes. The results showed that interaction technique did significantly affect total time spent using the application, but did not affect remembering and understanding. We discuss how lessons learned from the user study were applied to the VR version, what designs revisions needed to be made, and overall usability. Lastly, we summarize the experiences and evaluations from the case study by listing design guidelines for creating educational virtual environments from existing 2D information records.

Keywords: Virtual environments · Virtual reality · Educational technology · Construction safety

1 Introduction

Construction site accidents can result in human injury or fatalities, and even in the most benign cases, are costly for companies. On average, it has been estimated that construction companies could save $42,000 for each prevented injury or illness resulting in lost time, or $1,450,000 for each avoided occupational fatality [15]. While identifying hazards is an important aspect of reducing on site accidents, emphasis should also be placed on the design for construction safety concept. The concept has been linked to prior fatality investigation reports, suggesting that incidents can be avoided by considering construction site safety in the design of the project [3]. Similarly, Saleh et al. argue that teaching accident causation to engineering students may prevent recurrences of failures in engineering systems by both reinforcing safety requirements and empowering students to advocate system safety at a multidisciplinary level [24].

While construction incident reports can be reviewed and presented for educational use, their primary purpose is to record any details associated to the accident. They are thus highly descriptive, overly detailed, and lack a useful narrative for understanding the entirety of the accident. For this reason how and why the incidents happened aren't always intuitive, often resulting in instructors assigning a report to be read and later conducting a discussion. This approach engages students in the understanding of incident factors, but to be effective, requires a teacher or collaborators to participate. Even still, students might have difficulty conceptualizing the accidents without sufficient on site experience [23, 27].

As a highly interactive medium, educational virtual environments offer opportunities to engage students in memorable experiences that represent concepts in unique and meaningful ways [29, 14, 31]. Many researchers have suggested that virtual reality (VR) could have educational value for conveying spatial concepts that are difficult to comprehend (e.g., [31, 6, 8]). VR can also provide the ability to simulate scenarios that could not practically be experienced in normal life. Prior research in construction education have implemented these techniques to teach construction safety education concepts—such as safety protocols and hazard recognition—supporting the value of disseminating content via a digital application [9, 22, 16]. However, it is not clear what level of interactive control should be used to keep participants engaged without having to spend too much time familiarizing themselves with the nuances of the application [9, 4].

Our research addresses the need for long-term incident prevention, by introducing a single-learner VR educational application to contextualize accident causation and safety procedures (see Figure 5). The application is grounded in the results of a case study in system design, wherein we question how to effectively translate raw incident reports into a meaningful 3D educational experience. We developed a system framework leveraging educational modules that integrate relevant information from two Occupational Safety and Health Administration incident reports into a contextualized virtual construction space. The modules provide visual unification of the essential report details in various formats (text, numerical tables, static images, and spatial diagrams). We used the framework to develop a desktop version of the application and conducted a user study testing the effects of interactive control on learning behaviors and outcomes. The results of the study established a baseline understanding of the usability of our application. Lessons learned were then applied to the final VR version.

Through our educational application, we aim to allow students to be able to better understand the fundamental elements of construction safety by reviewing real examples in an engaging format. By presenting our advancements and development of an VR application for construction education our work contributes the following: (1) design guidelines from our case study of integrating incident report information in an educational 3D environment, (2) empirical results from a controlled experiment studying the implications of interaction techniques in a desktop application, and (3) usability studies with both VR and desktop versions of the application.

Fig. 1. The desktop application (left) and VR version (right) used different presentation formats for data annotations.

2 Related Research

Many researchers have discussed the potential benefits of 3D virtual environments for educational purposes (e.g., [30, 31]). VR can increase the level of realism by surrounding the user with a multitude of sensory information, thus replicating conditions similar to the real world. Additionally, stories or scenarios can also be added for users to take part in [28]. Taking advantage of these interactions in educational applications may lead to increased user engagement.

Researchers have explored how to design educational applications in many different disciplines. One well known example is *ScienceSpace* [6], which uses VR to teach science concepts such as Newtonian physics and electromagnetism. In work focusing on mathematics education, Roussos et al. used a virtual playground to teach numerical fractions through interactions with 3D animated characters [21]. Focusing on history education, Singh et al. [26] demonstrated the use of mobile augmented reality to contextualize evidence of historic events into real-world sites through an interactive detective experience. Furthering interactive engagement, Bowman et al. [4] conducted a study suggesting virtual environments (VE)s can be useful for better understanding the relationship between spatial and abstract information. Their study emphasized the importance of enabling interactive control that allows users to move freely and efficiently around the environment but without disorientation.

Researchers have also studied whether advanced display and interaction technology of VR might provide benefits for cognitive tasks. For instance, Ragan et al. [17] found improved recall when abstract information was presented at different locations around participants in a VE rather than only at the same place. This study showed evidence that participants were using spatial strategies with the VE to assist in memorization. In other work, a study by Ragan et al. [19] found significant improvements for a VR system using higher-fidelity features (higher field of view; better fidelity of visual view; and more surrounding screen space) for a memory task, demonstrating potential benefits of using immersive VR technology for certain types of learning scenarios. In later research comparing an immersive VR system to a similar system with limited display functionality enabled, researchers found evidence of improved memory of information locations in a VR environment with data annotations distributed throughout a virtual cave system [20]. However, this study also found participants experiencing worse sickness when using more interactive control techniques for 3D travel.

Challenges with 3D travel and control is especially important given that a high level of interactivity is one of the common claims for the educational benefits of VR [31]. If too much focus is given to interacting with the environment and how to operate the controls, the learner might be distracted from the learning content, which could negatively affect learning outcomes [18]. Determining the ideal level of interactive control for any educational application can be challenging and largely depends on the specifics of the application and the learning objectives. This becomes especially important for 3D applications due to the wide variety of possible ways to interact within it [31].

Virtual simulations can also be beneficial for safety. Real on-the-job hazards of construction safety training can be avoided by utilizing VEs to simulate the construction environment for off-site training. For example, Perlman et al. [16] developed a virtual construction environment that could be toured in a preset order using a VR CAVE system. They tested how well superintendents could identify hazards and how well they perceived the risk level. Often, emphasis is placed on learning how to identify hazards because it can be taught as a game to increase engagement, and scores can be used to assess participants' progress [13, 1, 10]. Alternatively some have taught operation procedures [7, 11]. Research by Le et al. covered both hazard identification and operation procedures in separate VEs by first having a discussion over incident report contents between students and teacher in a virtual classroom [9]. Results from their preliminary evaluation showed that instructors were required to provide more input and that it took time for students to adjust to the controls. Overall, the findings of prior research supports studying how to contextualize incident reports in VEs and how interactive control affects learning outcomes.

3 Application Design Framework

In this section, we present the resulting application design framework as part of the case study in system design.

3.1 Incident Reports

The framework we used to design our educational application consisted of incident reports by the Occupational Safety and Health Administration (OSHA). These were used because they had public accessibility and similar objectives in trying to help people working in the construction industry identify problems in construction design. For our case study, we chose to review two reports to understand how we would represent different types of information consistently.

From our review, we found that incidents did not occur as a result of one persons actions, rather an accumulation of design flaws and not following safety operations. In the first report, a wall collapsed in 2013, killing two workers and injuring one. This was a result of structural support rods in the wall not being properly placed, no actions to remedy the situation, and inadequate design and quantity of braces used to support the wall. The second report also occurred in 2013, when an overhead crane collapsed. One worker was killed and eight were injured. The accident was the result of poor structural design, failure to conduct a load test, and key participants not properly reviewing the design. We chose to describe accident causation by noting key participants, incident factors [27], and dates.

3.2 Learning Objectives

Our educational objectives were to have the users learn (1) the factors leading up to the accident, (2) proper procedures, and (3) details of the construction site and project. Following the construct of cognitive processes from the revised version of Blooms taxonomy [2], the application's format was designed for the user to remember and understand these objectives. By contextualizing information using spatial locations of 3D objects, text, and the objects themselves we encouraged exploration, which in turn could increase engagement. This design choice also introduced spatial information, an automatic form of information processing [12]. We spread the information out into key areas when possible and grouped related information as lessons that had a beginning and end.

3.3 Application Development

We first began developing a desktop prototype of the educational application. The hope was that by easing usability and accessibility for students in common educational settings, flaws in the design could be more apparent. The software was implemented using Unity's game engine with assets modeled in Autodesk Maya. The setup consisted of a screen/monitor and a standard keyboard and mouse for input. Annotations, menus, documents, or images in the desktop application were displayed as a 2D overlay. We discuss the necessary revisions in information display and input control for the VR version in Section 5.

Development followed an iterative process that involved continuous updates between the virtual environment and presentation of the learning content. Frequent informal evaluations of the system framework on prototype applications were conducted to help identify issues for improvement. Testers had few comments regarding the visual aesthetics or how the information was conveyed, but made it clear that how they explored and interacted with the environment to access information influenced their willingness to learn. These preliminary findings demonstrated how basic choices in information accessibility and control could influence the educational experience. Based on this work, we later refined the application to a working state by focusing only on the virtual environment contextualizing the masonry wall collapse.

3.4 Data Contextualization

The data in the reports consisted of text, on-site images, construction drawings, documents, and data tables. Our goal was to include as much of the source information as possible with the intention of observing which types of information were of most interest and value to learners. To contextualize the report, we designed virtual environments to reflect the construction site in appearance and layout, changes in time, and the inclusion of embedded images and text. We discuss our findings and design outcomes after the iterative development and testing process.

To give the user a sense of being on the site, it was important to show the entirety of the site despite lack of detail for areas not related to the incident. We modeled the environment to scale when information was provided, and we used construction standards to approximate dimensions when they were not specified. To address the problem of the environment feeling empty, relevant assets were placed throughout the site to aid in the creation of a more meaningful setting.

In both incidents, the actual accident occurred in a matter of seconds. Yet, when looking at the dates provided in the reports, the factors leading up to it often happened weeks to months prior. This provided a major challenge for application design—it was necessary to represent facts, spatial content and changes over a large period of time. Our solution was to create time steps for periods of time where key events or problems occurred. The application included the ability to switch between time steps and observe the corresponding changes in the environment and its structures. Figure 2 shows images demonstrating the key time steps and environmental changes of the incidents. For example, the masonry wall collapse is visually represented in three steps: improper installation, inadequate brace placement and design, and then the collapsed wall.

The system showed sequential events within a time step through the designed lessons. In the same example of the masonry wall, the lesson for the first timestep began with the environment showing misplaced straight support rods and a virtual character of the masonry contractor who first noticed the mistake. Upon

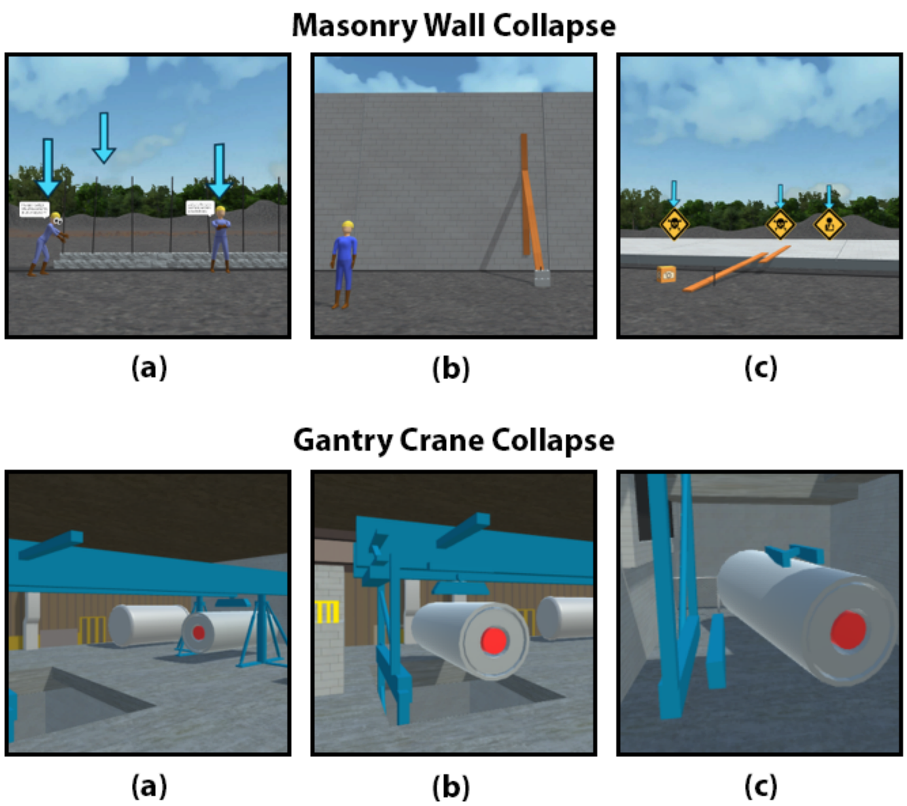

Fig. 2. Screenshots from the two accident scenarios showing key time steps.

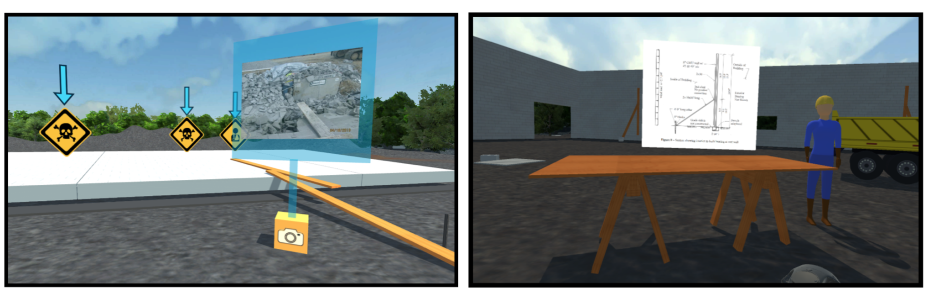

Fig. 3. Image cubes that open when interacted with(left) and a table showcasing 2D virtual documents (right).

the user interacting with both assets, a new lesson would start. The environment would change to then show the bent support rods with the general contractor proceeding with construction despite warnings. Lastly, the inspector was shown making no note of the mistake. Each asset or event within a lesson was explained via textual annotations.

All reports included certain pieces of information (e.g., sample documentation and images of construction drawings) that could not easily be shown through 3D representations in the environment. Such information was presented using annotations, through a menu, or as virtual 2D documents. To provide context while presenting the disparate collection of documents and images, relevant items were grouped together at locations to help provide memorable access. Photographs of the construction site were also integrated into the 3D space by placing them in the locations corresponding to where they would have been taken in the virtual environment (Figure 3, left).

The virtual environments were designed to facilitate gathering information about the incident and proper (or improper) construction procedures. Interacting with assets within the environment revealed associated information in a contextualized presentation. To promote interest in key areas, large oscillating arrows appeared over items that could be interacted with. We included a mini-map with a top-down view of the site to assist in understanding location and orientation. The locations of key areas, and embedded photographs were also shown on the mini-map. Additionally, a menu was made available to select a timestep and initiate a lesson. Items not related to the lessons were used to display additional information from the report such as images of the construction drawings or photographs of the site.

4 Study on Learning Behaviors and Outcomes

It is important to understand the implications of different degrees of interactivity and techniques supported for interactive control when using interactive media, as unnecessary or difficult interactions can have negative implications [31, 18]. For this reason, we conducted a user study to test how different interactive techniques influence learning behaviors and outcomes. The goal of the study was to investigate the appropriate level of interactive control for information access in the educational prototype. For experimental control and simplification of the procedure, the study used the desktop version of the application with only the virtual environment contextualizing the incident involving the partial collapse of a masonry wall. This was done to avoid possible distractions that often comes with the novelty of VR and the head-tracked experience. By only including one virtual environment, we were able to test user's understanding and memory of the content. The results of the study were used as baseline understanding that was later compared against the VR version.

4.1 Study Design

The study focused on interactive control for travel and information access, which determines the method of exploring the environment and the limits on where participants could go at any given point in time. The study followed a between-subjects design to compare three versions of interactive control, which we refer to as *active*, *directed*, and *guided*. The *active* mode allowed for full navigational control, which permitted users to move freely to any location within the environment. The application used the mouse for orientation view control and the keyboard (WASD) for positional movement. Similar to the preset tour of a construction environment by Perlman et al. [16], the *directed* mode was a semi-automated tour of the environment's key locations. In this mode the user was placed in positions aligning with content or lessons within the environment in a predefined order. While the user had no control of their position, they could change the orientation of the camera and choose when to proceed to the next position via a button click.

The *guided* mode was a hybrid of the *directed* and *active* modes. Participants had control of movement in the environment but were limited to contained areas at predetermined sites. The sites were chosen as areas containing groups of information for the application, and participants could not travel outside of these areas before all groups of information were discovered. We hypothesized that the *guided* mode would yield better results because we expected the limited freedom would ease cognitive load of navigational decision making while still allowing some freedom of interactive viewing.

4.2 Procedure

The study was approved by our organization's Institutional Review Board (IRB) and took no more than 90 minutes from start to finish. We recruited 30 participants, limited to university students over the age of 18. Almost a third of the students were from the construction science department. Each participant used the desktop version of the application with one of the three types of interactive control. Participant's first completed a short background questionnaire. They then were then asked to spend at least five minutes in a tutorial VE to increase their understanding of how to navigate the VE and interact with its content. Before beginning the main educational activity, participants were told that they would be tested on the information found in the environment and asked to read a short summary of the incident. Participants were given 20 minutes to explore the environment with the option to finish early or to restart the exploration at any time. Verbal assistance about the controls or interface were given if requested.

Immediately after participants finished using the application, they took a thirty-eight question quiz on paper. The quiz covered information found within the environment and tested the cognitive processes of understanding and remembering, following the Anderson et al. [2] revision of Blooms Taxonomy. There were 38 questions in total: 29 multiple choice questions on details and procedures to assess how much participants remembered and 9 short answer

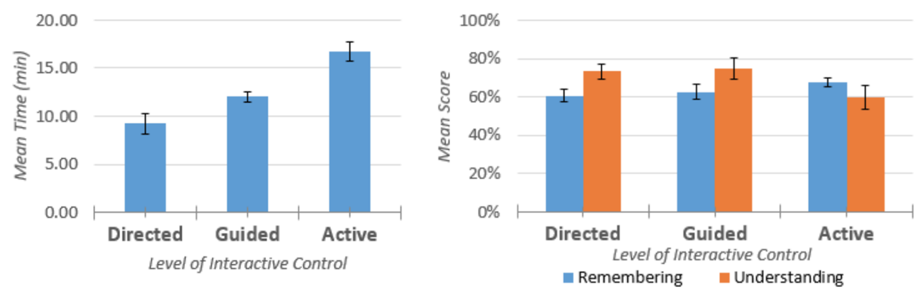

Fig. 4. A summary of study results: mean completion times (left), scores for remembering and understanding questions (right).

questions to assess their understanding of the incident events and factors. Examples of questions include: "Who designed the brace installation?", "Where should the rebar be located in the CMU brick?", "What was wrong with the braces?".

Participants then proceeded to fill out the industry standard systems usability scale (SUS) questionnaire [5]. A closing questionnaire was also administered, allowing them to provide additional comments about their experience and usability of the application. Finally, a brief interview was conducted should the participant want to elaborate on their comments.

4.3 Results and Discussions

In our study we tested behavior and learning outcomes from participants using our application by gathering both quantitative and qualitative evidence. We hypothesized that an intermediate level of interactive control (in this case, the *guided* condition) would produce the best learning results by balancing freedom of exploration with ease of use. In conjunction, we wanted to get a baseline understanding on the usability of the desktop application to compare against the VR version. We present our findings, analyzing quantitative results using Analysis of variance (ANOVA) tests and summarizing qualitative results.

Overall we found no evidence towards our hypothesis because there was no statistical difference in post-study scores for either *remembering* or *understanding* question types (see Table 1). However, it is interesting to note, that there was a significant statistical difference for the average time participants spent using the application (see Figure 4). Further analysis using a post-hoc Tukey HSD test found the time for the *active* condition to be significantly higher than both the *directed* and *guided* conditions. We speculate that while it may appear that the *directed* condition is the best choice given higher scores for less time, further research should be done to understand long-term recall. These results are also intuitive; given the freedom to continue viewing the virtual environment within the 20-minute time limit, participants chose to explore.

Table 1. Effects of interactive control on learning outcomes and usability, statistical analysis results.

	Metric Range	Mean Score			F(2,27)	p
		Directed	Guided	Active		
Understanding	0-100%	73	75	60	2.207	0.130
Remembering	0-100%	61	63	68	1.165	0.327
Time (min)	0-20	9.20	12.00	16.70	16.315	< 0.001 *
Usability (SUS)	0-100	81.25	80.25	75.50	0.530	0.595

The mean SUS scores ranged from 75.50 to 81.25. Since these were above what is considered an average usability score of 68 (see [25]), we consider the application to be reasonably well-designed for its purposes. We found no statistical difference in the mean SUS scores across the three conditions.

We observed that participants' goals and viewing behaviors varied based on interactive control on navigation. The participants of the *directed* group did not seem to rotate the camera, choosing the default orientation with emphasis on reading the text annotations. Participants in the *guided* group treated the application more like a game to find all interactive assets, sometimes verbalizing their desire to move on to the next area. In the *active* group, participants would randomly choose an area to visit, go to the next, then revisit the areas to find information they might have missed. Participant feedback was generally positive towards the application. Some commented that they liked the story telling aspect of the visual information mixed with textual annotations. Some critiques of the application included concerns distinguishing which elements of the environment were interactive and wanting a clearer role or purpose in the construction scenario.

5 Extending to Virtual Reality

For the last stage of the case study in designing an educational 3D application for construction safety, we developed a VR version of the application. For our goals of supporting information contextualization, the immersive format offered the benefits of being a highly engaging and appealing medium. However, VR is also generally expected to utilize a degree of interactivity. Thus, we followed our design framework for contextualizing incident reports and used the results from the study on learning behaviors and outcomes to guide the necessary design revisions for a VR version of the application.

5.1 VR Design Updates

The VR application was developed for use in an HTC Vive system with a head-mounted display and one wand controller. Since the desktop application relied

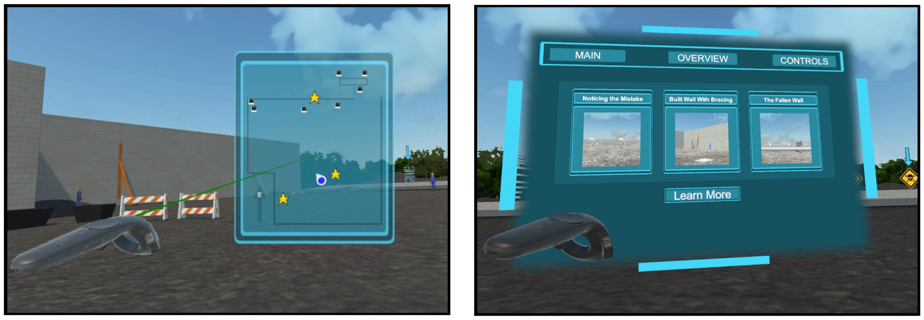

Fig. 5. Screenshots from the educational virtual environment show the map interface (left) and menu design (right) in the VR version of the application, while the virtual construction site is in the background.

on mouse and keyboard interaction, the VR application required support for the new tracked input devices. It was also necessary to make design revisions towards relaying textual information because head-based rendering was enabled for viewing. To promote exploration, we decided to prioritize engagement and interest. Referring to the usability results of the user study (see Section 4), we decided to lean more towards highly interactive travel. Though this choice might have led to increased complexity of interaction, we felt the activity and contextualized content would be more meaningful if learners felt more willing to continue to explore the 3D space. Therefore, learners were not limited in travel area and could move wherever they wanted.

We limited the number of wands to one to reduce the cognitive load on the learner. Raycasting with the wand was used to select interactive items for further detail in the VR version rather than mouse selection. Users had the option to physically walk within the tracked area of the real world room to be more precise when trying to investigate particular objects. The tracked area was represented in the VE as a semi-transparent boundary that would display when the user approached a corner or edge. The virtual tracked area could be moved by using the directional buttons on the wand or trigger clicking the mini-map to warp to a desired location (Figure 5, left).

In desktop version of the application, textual information from lessons were 2D annotations overlaid on the screen. Since this was no longer feasible in the immersive format, the VR version used hand-anchored text displays attached to a pivot point just above the controller and billboarded to always face the users view. The menu was accessed by clicking the top button the wand and was presented on a 2D surface at a predefined distance from the user (Figure 5, right). While viewing it, the virtual tracked area was constrained. We opted against using the prior two techniques for the mini-map because we wanted to user to have the ability to trigger click it and warp. We instead used a heads up display that could be toggled on or off by pressing the grip buttons on the controller. Figure 1 shows an example of interface differences for presenting annotations.

5.2 Usability Observations and Feedback

To get a better idea of the usability of the VR application, we conducted a small informal usability study of five participants. The procedure was similar to the study on learning outcomes and behaviors. Participants were asked to use a tutorial application to familiarize themselves with the controls, then asked to explore the environment however they wanted. For this informal study, we did not ask participants to do a post-study questionnaire on the content. We did however, ask for feedback on the application, particularly what stood out. We also observed how they used the application, navigated the environment, and their ability to find the learning content. Overall, the participants spent more time using the application, had difficulties with interactions, but enjoyed using the VR application to explore the environment.

Observations regarding the order participants chose to view the lessons using the active level of navigation control for the desktop application carried over to the VR system, but with one difference. Instead of searching for assets to interact with, participants were more interested in just looking at the environment. One participant in particular, used the touchpad to move the virtual tracked area forward while looking down at bricks. Many users appreciated trigger clicking the mini-map to warp to specific locations, but wanted more precise control. They tried to get closer to the targeted location by using the touchpad to move the virtual tracked area, but often overshot. A few times we observed participants moving the virtual tracked area back and forth to get into the correct position. It is interesting to note that participants rarely physically moved around to get a better look at objects in the environment which would have solved precision issues. We suspect they were uncomfortable moving around without knowing the exact layout of their real world surroundings. In the tested application participants could trigger click interactive assets to initiate lessons, but many preferred using the menu.

We also noted that the display fidelity and ease of participant location and orientation influenced what assets were looked at. For example, photographs of the environment were interacted with less frequently due to the trouble of precisely positioning the virtual tracked area and participants unwillingness to physically position themselves in a way that allowed them to align the photograph with the environment. We also found that virtual documents with high amounts of text and details (Figure 3, right) were far less useful in VR due to (a) the lower resolution of the display system, and (b) difficulty in aligning the virtual 2D documents for reading.

We identified several pitfalls in the newly designed user interface. Many participants physically and verbally expressed confusion in using the buttons on the controller to bring up the menu and mini-map. For example, one button was assigned to opening the menu. Later, when a lesson was started, the same button was reassigned to acknowledge that the information had been read. We also observed that the user would open the mini-map and forget to turn it off, leaving it to block the center view of the HMD. The textual information placed just above the location of the controller, always aiming toward the participant was used, but not in the way we expected. We designed the interface so the participant could lift an arm to select the interactive asset and then keep it there to read the information, allowing them to read the text while preserving their view of the asset for context. However, such use was not commonly observed; due to comfort and fatigue of arm movements, participants would often lower their arm and look down at the text, taking attention away from the asset.

6 Discussion and Conclusion

We presented a novel VR application for construction safety education. Our research followed a case study in the design and development of an educational 3D application with both desktop and VR versions. By using information from real OSHA incident reports, we developed a design framework for contextualizing raw report data into a meaningful 3D space. Our framework demonstrated techniques for integrating different forms of incident report information into a virtual environment.

We used iterative application development in our case study with both formal and informal user testing to improve design decisions and functionality. A summary of the key study findings are shown in Table 2. Through an experiment with varying levels of interactive control for travel and information access, we found participants were more likely to spend an increased amount of time in the application and be engaged when adopting a higher degree of control. While this effect is likely related to technique effectiveness for information access, the finding also demonstrates that control methods may also influence total time and attention given to content in an educational application. Follow-up research would be needed to further investigate the reasons for the outcomes.

Table 2. Properties of Interactive Control Levels

	Directed	**Guided**	**Active**
Learning	linear	linear	non-linear
Controls	semi-automated tour with control of the camera rotation and pacing	blend of directed and active, limited to an area	full navigational control
Qualitative Results	Pressed button, read information, repeat	Finished area by area, like completing levels	Participants not sure where to go, more exploratory
Explore Time	Least	Middle	Most

The results of the evaluations and case studies helped to motivate the decisions for taking advantage of VR's interactivity for an engaging educational experience. Overall, our approach resulted in the development of a new educational application, and the usability results from our studies provide evidence

Table 3. Summary of Design Guidelines

Data Preperation	Understand the data within the construction incident report. What events led up to the incident? What are the types of data?
Learning Objectives and Storyboarding	To design how the application will work the learning objective should be defined. Consider if they will be learning new knowledge, comprehending, analyzing, or creating. The learning objective should shape how the application will work.
Choosing a System Device	The system device you choose will influence the interactions within the environment. Types of devices can include a desktop computer or head-mounted displays for virtual reality. Some may increase engagement, but at the cost of familiarity of controls.
Visual Aesthetic	Consider using a simplistic, stylized, or realistic style as it determines the level of detail. The design may deviate, if it maintains a consistent look.
Representing Temporal Change	Contextualizing time in a static virtual environment is difficult and there are many ways to approach it. Make the changes in time clear for the learner to understand the progression of events.
Data Representation	The data can be represented through visual, textual, spatial, or audio representation. Deciding which one to use or how depends on the amount of data and resources.
Interaction Techniques	To access the information the user must interact with the environment. This could include selecting objects, an intuitive user interface, and/or navigation.

of general usability and design success. Based on the design process and the results of our evaluations with participants, we provide a summary of design recommendations for developing educational 3D applications for the purposes of contextualizing a construction incident report. Our guidelines cover data preparation, learning objectives and storyboarding, choosing a system device, visual aesthetic, representing temporal change, data representation, and interaction techniques within a VE. An overview of the guidelines are shown in Table 3. While not a definitive set of rules, others may use our results to help in the development of educational applications.

Although our results support a successful design and development process, our research is not without its limitations. Following iterative development, we conducted a formal user study with the desktop evaluation to help study approaches for interaction, but we did not conduct formal user study on the VR application. Future work will also require testing with construction students to better understand suitability for educational contexts.

Similarly, our experiment only assessed short-term recall with simple memory and understanding learning outcomes. Participants completed the knowledge assessment immediately after using the application. We are interested in extending our research by also testing longer-term recall (i.e., after several days or weeks). We suspect longer-term retention might provide more meaningful results as it could validate the correlation of increased engagement to recall and perhaps show whether or not a certain type of information (spatial, textual, visual) is better retained.

Another possible limitation is that although our approach focuses on the presentation of construction incident reports, this is only one method used to teach construction safety. Future advancement in this direction of research could also consider alternative design schemes for educational VR to present safety concepts in a meaningful way.

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