CONTEXTUALIZING CONSTRUCTION INCIDENT REPORTS IN VIRTUAL ENVIRONMENTS

A Thesis

by

ALYSSA MURIAH PEÑA

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	Julian Kang
Co-Chair of Committee,	Eric D. Ragan
Committee Members,	Tim McLaughlin
Head of Department,	Tim McLaughlin

May 2017

Major Subject: Visualization

ABSTRACT

Safety education is important in the construction industry. While research has been done on virtual environments for construction safety education, there is no set method for effectively contextualizing safety information and engaging students. In this research, we study the design of an application to represent construction accident reports provided by the Occupational Health and Safety Administration (OSHA). In a Case Study we designed and implemented two applications, each with a unique virtual environment to contextualize an incident report through space, visuals, and text. We also conducted a user study for how interaction techniques affect learning, focusing on the system device and varying levels of navigational control. From the user and case study results we present design guidelines for creating an interactive application to represent a construction incident report.

ACKNOWLEDGMENTS

I would like to thank my committee chair, Dr. Julian Kang, for encouraging me throughout my research. I am also thankful to my co-chair, Dr. Eric D. Ragan, for constant feedback and committee member Tim McLaughlin for insights on educational objectives.

I am thankful to all my friends at Texas A&M University, all the students who selflessly participated in my research, and my family. I am grateful to God for always being there. Most of all I would like to thank my mother, who always stood by me and inspired me to go further.

Last, I would like to thank Texas A&M University for providing an environment where I can be both creative and technical.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supported by a thesis committee consisting of Dr. Julian Kang of the Department of Construction Science, Dr. Eric D. Ragan of the Department of Visualization, and Tim McLaughlin of the Department of Visualization. All work conducted for the thesis was completed by the student independently.

Funding Sources

No outside funding was received for this graduate study.

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1. INTRODUCTION

1.1 Motivation

Safety is important in the construction industry. In 2014, there were 4,769 fatal work injuries reported. The injury rate slightly increased from the previous year at 3.4 worker injuries per 100,000 full time workers [1]. In addition to being dangerous, accidents are costly. On average, construction companies could save $37,000 for each prevented injury or illness resulting in lost time, or $1,390,000 for each avoided occupational fatality [2]. Construction workplace safety has improved over time, and the number of fatalities has decreased since 1994. Yet, the rate of injuries in construction has nearly plateaued since 2009 [3].

One way to further reduce injuries is to improve education about safe workplace practices. The Occupational Safety and Health Administration (OSHA) provides training, outreach, education, and assistance to better prepare and inform workers on safety. Many entry-level positions in the construction industry require a ten-hour OSHA course certificate that teaches about OSHA, the major safety hazards, and general safety and health management knowledge [4]. College institutions are also incorporating safety classes into their Construction Management degree plans (e.g., Texas A&M University [5], Washington State University [6], University of Florida [7]). Part of these curricula from university programs includes reviewing previous reports of construction incidents. Looking at past incident reports can be useful in teaching construction safety. Reading previous accounts can help students learn more about accident variety, better understand their consequences, recognize the limits of building models, and become more aware of possible research topics that might be considered for construction management [8]. Reviewing prior accidents and their causes can help prevent the same mistakes from occurring over and over again

[9]. Despite the benefits of reviewing past reports, accident reports can be difficult to conceptualize without experience in the field [10].

In the classroom, one common approach is for the instructor to assign a report to be read and then to lead a discussion amongst students to ensure they understand what happened and highlight the important parts. This approach engages students to discuss issues, but to be effective, it requires a teacher or collaborators to learn the material, and students still might have difficulty conceptualizing the accidents without sufficient personal site experience. Researchers have long explored alternative means of education to increase student engagement. For example, Hall et al. [11] created a board game to develop skills in building, finance, accounting, and OSHA regulations. More recently, research has shifted into 3D virtual environments for safety education (e.g., [12], [13], [14]). Virtual environments are beneficial for conveying concepts that are difficult to comprehend ([15]). For these reasons, our research investigates the use a virtual environment to represent the incident reports. We study design challenges and recommendations for the use of incident reports to create a 3D educational application to engage students as they learn more about the construction incident.

1.2 Objective

We wanted to create an application to represent incident reports in a 3D virtual environment with interactive features. However, every incident is unique and it would be wasteful to create an application specifically tailored to each report. Therefor our objective is to improve the dissemination of information by formulating guidelines for a interactive application that contextualizes the incident reports in a more visual format. We conducted a case study over the design and development of two applications representing two incident reports to investigate how certain design aspects affect the ability to communicate different types of incident information. The application designed in the case study were implemented using a desktop computer, keyboard, and mouse. Knowing that there are other system devices that may alter the interaction techniques we chose to conduct a usability study on a virtual reality version of the application. We also study the effect of different interaction techniques on learning by focusing on the level of navigational control. Our research provides a basic structure for contextualizing incident reports.

2. LITERATURE REVIEW

2.1 Virtual Environments for Education

While students can learn from traditional safety education methods such as reading assignments or class lectures, such approaches lack engagement with the content and are limited in their ability to support contextualizing the given information. In education, visual presentation can facilitate the cognitive process ([16]). Educational virtual environments can be useful for conveying concepts with spatial elements that are difficult to comprehend, and interactive media can increase student engagement through interaction with the environment [15, 17]. Another major benefit of educational virtual environments is their ability to allow students to easily repeat a lesson as many times as desired without risk of injury ([18]). There are multiple ways to present information in a virtual environment, some more effective then others. The key is to help the learner form connections through the data presented to them [19].

2.2 Prior Construction Safety Applications

Research in construction safety has recently shifted to serious gaming and training via virtual environments focusing on safety regulations, collaborative learning, hazard identification, procedures, and simulation. The applications also focus on immersion through use virtual reality and augmented reality or high fidelity visual aesthetics.

In past work aiming to leverage the benefits of virtual environments for construction education, a research team created a game called MERIT and conducted a study of how simulation could be implemented to create unique scenarios and promote collaborative learning [20].

Lin's team conducted a study on the development of a construction safety game using virtual environments, Building Information Modeling (BIM) and simulation [14]. The team focused on realistic graphics to increase student engagement. The learning content was based on hazards that could be found on the construction site. No formal user studies were conducted to test the effectiveness of the application or design choices.

Another study developed a safety education system in virtual reality and used a inactive, active and proactive learning approach. For the inactive approach, an instructor went over construction safety topics with a group of students in a virtual classroom. The students were then individually placed in a virtual environment to identify hazards mentioned in the virtual classroom as part of the active learning approach. In the the proactive approach, students were put into teams in another virtual environment and given a training task that prepared them for something that could happen in the real world. By exposing the students to the content that they needed to learn in the inactive phase, less emphasis was be placed on the content being taught in the virtual environment. While incident reports were looked over, it was in a classroom setting and under discussion with the students and professor. The education was test by conducting a user study of 20 participants evenly split into two groups. Group 1 used the application to learn construction safety concepts and group was taught under a traditional learning environment. Their preliminary evaluation suggested that instructors and students enjoyed the virtual version, but the study for cognitive workload was still in progress [12].

2.3 Environment Navigation

User engagement is good for cognitive learning and can be increased depending on how the user navigates within the virtual environment [17]. There is also evidence that memory recall associated with an object can be improved using interactive navigation [21]. However, it is up to debate how much interactive control should be given to the user. If too much focus is given on how to interact with the environment the user can deviate from the content trying to be taught. On the other hand, if no control is given the user may lose their sense of presence. A study was done solely to test fact memory, understanding, location recall, and landmark recall on interactive versus controlled navigation. Although they concluded that interactive control may have have negative consequences, the scope of the project was not specific to construction safety education [22].

Researchers who create virtual environments for education explain how the user will navigate the environment, but oftentimes no data is collected on whether or not that was the most effective decision. For example, one study had a point, click, and move interface that was implemented in two different ways. The environment was a clickable area where the user clicked to a location that they would like to go to and the overhead map was also clickable should the user want to walk somewhere not within viewing range. Although they made these choices to ensure the user could always go where they desired, no data was collected on the differing methods and how they fared against each other [23].

3. RESEARCH OVERVIEW

The purpose of our research is to create a set of guidelines for an application that contextualizes incident reports in a virtual environment with interactive features. In the context of this research, an application will consist of the system device, virtual environment, and interaction techniques. To create the guidelines we studied how the application design varies by incident reports and how interaction techniques affect learning. We developed two unique virtual environments each contextualizing an incident report to understand how to make design choices that apply to multiple scenarios. Although we primarily focus on a desktop computer, keyboard, and mouse for the system device, we conducted an informal usability study for a virtual reality version of one of the applications. We then collected qualitative and quantitative data to study interaction techniques, focusing on levels of navigational control.

3.1 Case Study in Design

We conducted a case study of the development of two applications to represent two incident reports to understand what design decisions needed to be made. We first analyzed the information in the report and then created learning objectives. Then using Maya and Unity, we conveyed the information through visual details and text within a virtual environment. The process began with side by side development of the application then staggered when implementing environment navigation. By conducting this study we were able to understand what features could transfer over, different types of visual representation, and a basic structure of the applications' function.

3.2 Usability Study: Virtual Reality Application

The most influencing factor for application design and interaction techniques is the system device, because it changes the input controls. Virtual reality is know for increased engagement because the user is placed into a 3D space. However, learning how to use the system can be difficult, especially if the participant has no prior experience using virtual reality. For this reason we conducted an informal usability study to understand how changing the system device would affect our design choices and participant's learning.

3.3 Experiment: Interaction Techniques

The level of navigational control directly affects how the user will interact with the environment. To study these affects on learning we designed an experiment to test varying levels of interactive control for a desktop computer system. We created three levels; directed, guided, and active. A user study was conducted to gather qualitative and quantitative data on the participant's comprehension and knowledge of the material.

3.4 Design Guidelines

The design guidelines for the application were created from the results of our case study in design, virtual reality usability study, and interaction techniques within the virtual environment. We also referenced previous research. There is is no right way to design the application which is evident in our study results. Our goal was to provide a starting point in design that can be iterated upon in the future.

4. CASE STUDY: DESIGNING APPLICATIONS TO REPRESENT CONSTRUCTION INCIDENT REPORTS

4.1 Summary

To create an application to contextualize construction incident reports we must consider how the variations in incident reports influence the design of the application. In this Case Study we designed and developed two applications, each based on construction incident reports. We discuss converting incident report information into data, application functionality and implementation, design choices regarding the virtual environment, and environment navigation. The applications were developed for use on a desktop computer with a mouse and keyboard.

4.2 Goal

The goal of this study was to design and develop two applications to understand two different incidents reports. Doing this helped us keep them similar in function and understand how to design the virtual environment to convey the data.

4.3 Incident Reports

We chose to use construction incident reports found on OSHA's website. The incidents mostly resulted in worker fatalities and multimillion dollar losses. Similar to our research goals, they made some of their reports public in hopes of reducing future incidents, fatalities, and serious injuries. The reports are an effort to help people working in the construction industry identify problems in construction design, project management, and management of field engineering changes. In addition, by only using their reports we had consistency in the document structure. We chose two cases based on the amount of details provided and the scale of the site where they took place. We avoided cases that were older than 2012, required a lot of 3D modeling for deformation of structures, or didn't have a clearly defined space for the user to explore.

4.3.1 Case 01 : Partial Collapse of a Masonry Wall

The first incident report is about an accident that occurred on April 18, 2013 when a wall collapsed, killing two workers and injuring another. The structural support in the wall was not properly placed, no action was done to remedy the situation, and there were inadequate braces to hold up the wall. We selected this case, because it had drawings of the entire site layout and the subject matter was what most people might think of when thinking of a construction site. It was also compelling to show people how walls are built.

4.3.2 Case 02 : Temporary Overhead Crane Collapse

The second incident report is about a overhead crane collapse that occurred on March 31, 2013. One worker was killed and eight injured. The accident was the result of poor structural design, failure to conduct a load test, and key participants not reviewing or question the design. Different from Case 01 where a masonry wall collapsed, we had to consider that most people don't understand how crane's work or what goes on in a nuclear plant. Also, there there was no clear drawing of the layout and many details had to be inferred through images.

4.4 Accident Causation

While each report included a conclusion section to summarize the factors leading up to the incident it was unclear how to make sense of it in a transferable way. What remained in both was key participants, incident factors, and dates.

4.4.1 Key Participants

Each report included a section regarding the key participants of the case that contributed to the accident directly or indirectly. We summarized the key participants to help us understand that there were multiple people involved with the incident events, not just one person (Table 4.1, Table 4.2). We chose to only use the titles of the key participants when discussing events, because the company name didn't directly contribute to what happened.

Title	Participant
Owner	Goodwill
Architect	H. Michael Hindman Architects (HMHA)
Structural Engineer	EMC Structural Engineeers (EMC)
General Contractor	Solomon Builders, Inc.
Masonry Contractor	Shannon Tayes dba Tayes Masonry of Smithville
Structural Testing and Inspection	Beaver Engineering, Inc.

Table 4.1: Case 01 Key Participants

Title	Participant
Owner	Entergy Arkansas, Inc.
Agent / Operator	Entergy Operations, Inc.
Sub-contractor	Siemens Energy, Inc.
Sub-contractor	Bigge Crane and Rigging Co.
Independent Contractor	DP Engineering, Ltd.

Table 4.2: Case 02 Key Participants

4.4.2 Factors

In many accident cases, there are multiple factors that led up to the the accidents and their undesired results. The cause of the accident needed to be identified to help us identitfy the essential information. We chose to use the methodology from Suraji's research to categorize the incident factors and events. Over 500 reports were looked over to develop a the constraint-response model to track the behavior of all participants that may build up to the accident while taking into account constraints that might have caused the behavior. We used the model's classifications for proximal (direct contribution) factors and accident events/ [10]. With limited information, we were unable to include distal factors (indirect contributions).

The model was useful for systematically defining the incident events, but lacked in clarification. Sometimes we weren't sure what category an event should be placed under. This mainly happened the higher up the mistake. For example in Case 02 (the partial crane collapse) a big problem was the other key participants lack of communication with the main contractor. While the model has a classification for inadequate communication or coordination, it seems to be regarding employees on site. It would be more beneficial to use OSHA violations as the basis for incident events, but the reports only mention a few, sporadically.

Classification	Report
ICP-0: Inadequate site investigation	The inspector did not report the misplaced rebar
ICP-10: Inadequate structural design for temporary support structures	The braces were not up to code
Sub-The braces were not up to code	Misplaced rebar and braces removed prematurely.
ICO-07: Improper instruction to operatives	Contractor knew about the rebar, but instructed masonry contractor to proceed.

Table 4.3: Case 01, Proximal Factors

Classification	Report
UE-07: Structure disturbance	Wind gusts of 33mph
UUE-12: Structure Collapse	East wall collapses
UO-01: Fatality	Two employee
UO-03: Minor injury	One employee

Table 4.4: Case 01, Accident Events

Classification	Report
ICP-06: Inadequate planning and design of plant or equipment operation	Was designed to 100% load not 125%
IOA-09: Improper working position	Employees located in fall zone
IC0-11: Inadequate communication or coordination	No one reviewed or questioned Bigge's design.
IOA-13: Omission : missing something from sequence of steps	A load test was not conducted

Table 4.5: Case 02, Proximal Factors

Classification	Report
UUE-12: Structure Collapse	Temporary crane collapsed
UO-01: Fatality	One worker
UO-03: Minor injury	Eight employees
UO-03: Minor injury	One employee

Table 4.6: Case 02, Accident Events

4.4.3 Event Chronology

For each case, the accident occurred in a matter of seconds. While there may have been hints that the structure was about to collapse, the action was immediate. Yet, when looking at the the dates provided in the reports, the factors leading up to it could have happened months prior. We made a list of all the dates mentioned to understand the timeline of the incident (Figure A.1). This was helpful, because the report did not always present the information in chronological order. We then highlighted the important dates to understand what assets we would have to create. For example, Case 02 mentions assembling the crane, preparing it for a load, starting to transport the load, and then the collapse. We would have to model and position the crane for each step as well as change the position of workers if necessary. A few of the dates were vague and others unnecessary for the big picture (i.e. when someone conducted a purchase).

Earliest	First Factor	Accident	Construction Duration
08/2012	03/2013	04/2013	1 Month
06/2012	09/2012	03/2013	2 Days

Table 4.7: Case 02 : Partial Collapse of Temporary Overhead Crane

4.5 Data Preparation

Upon understanding the key factors that led to the accident we visually categorized this information by highlighting the document based on a loose set of rules; green was essential, yellow contributed to the environment, purple was misc., and so on (Figures A.2, A.3). Our goal was to contextualize the entire report using a virtual environment, yet a lot of the information was repeated or irrelevant to the main components of the incident. If we only kept the essential details, we would only be taking into account a third of the report. The goal of our research was to contextualize the report in it's entirety, therefore the supplemental information had to be included. Therefore we wanted to represent as much information as possible. Our environment, just like the incident report, would include information that the user could decide whether or not they wanted to skip over. We broke

Figure 4.1: Incident Report Imagery (Left: Case 01, Right: Case 02)

the information down into three categories; text, images, and drawings.

4.5.1 Images

Images of the construction site accounted for almost a third of the incident report and were the easiest way to form a mental image of what the construction site really looked like (Figures 4.1). They were helpful for creating the visual details of the environment, but there weren't enough to fully recreate the environment because they only showed one perspective.

4.5.2 Drawings

Each report included construction drawings or plans of what was being used or built. The problem that frequently occurred was the low image resolution. It was hard to make out the exact dimensions. Our workaround was to find at least one or two dimensions and use the scale of the dimensions on the paper to calculate the other dimensions. Also, they didn't always match the images of the construction site and there was always the possibility that deviations were made. Still, they were helpful for maintaining a sense of scale and layout.

4.5.3 Text

Text was the primary source of information. It was useful for telling the story with the description of events and quotes from employees, but was often redundant, long, and unnecessary. The text also depended on the investigator that wrote the paper, making for inconsistent styles of writing.

4.6 Application Functionality

In our literature review, we discussed the benefits of virtual environments for increasing user engagement. Before proceeding with development of the virtual environment and it's interactive features we had to come up with a purpose for the user to explore it.

We briefly considered a serious game with scores and detective based clue seeking to encourage the user to learn more about the incident. First, the user would explore the environment after the incident. Upon finding all the information they would be tasked to exploring the environment before the incident occurred and answering questions placed throughout regarding correct procedures and case information. Figure 4.2 is an early prototype of the user clicking the brace to answer a question pertaining to the case. The top right hand corner shows a score to let them know whether or not they answered correctly.

There were a few problems with the serious game prototype. Our primary goal was to create a tool to help people learn and understand the contents within an incident report. By turning it into a game, we were forced to pinpoint what exactly we wanted the user to understand and how it could be applied to a different scenario. However, for the scope of this project we were more concerned about how to contextualize the information. Another issue was that the user would be restricted to one time period and the incident events happened at differing times. It might have been able to work if the objects from environment remained in the altered environment (i.e. the contractor was always at the same location regardless of time), but would have been jarring.

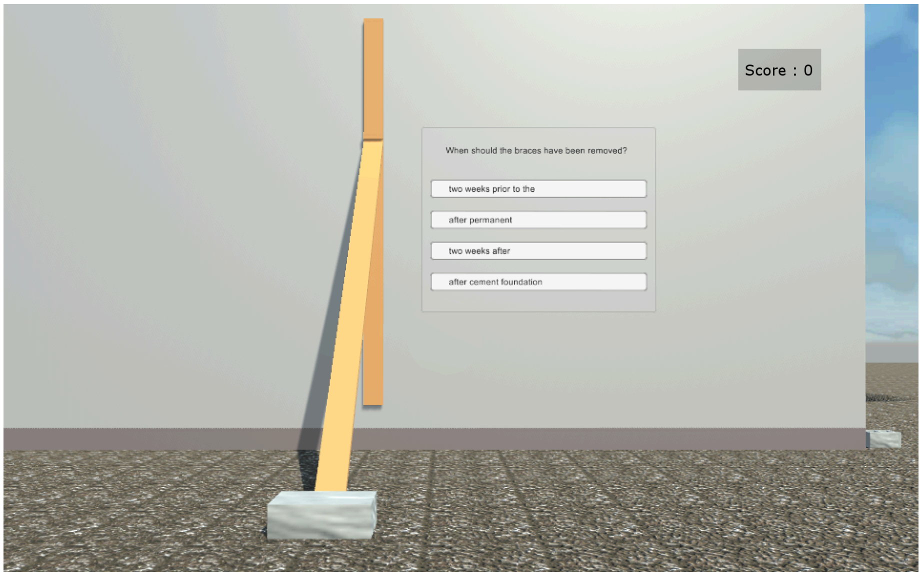

Figure 4.2: Game Exploration

We took a step back to review the data from the report and set a learning objective. From the previous section our data was categorized as essential, supplemental, environmental, and misc. details. We knew we wanted to contextualize as much information as possible and to test some our design choices we would eventually have to collect data on the user's comprehension and knowledge. We wanted to know if the user understood what happened and if they could recall the information. For comprehension we decided to create mini interactive lessons on the incident events and proper procedures. It was important for us that the user not only understand what went wrong, but how it should have been done. The remaining information mostly consisted of supplemental and misc. details such as the key participants or structural drawings of the wall in the form of plans and documents. We decided to include it in some way should the user seek after it. We called the incident events, correct procedures, and plans and documents our three key learning subjects. In the following sections we discuss implementation and design choices.

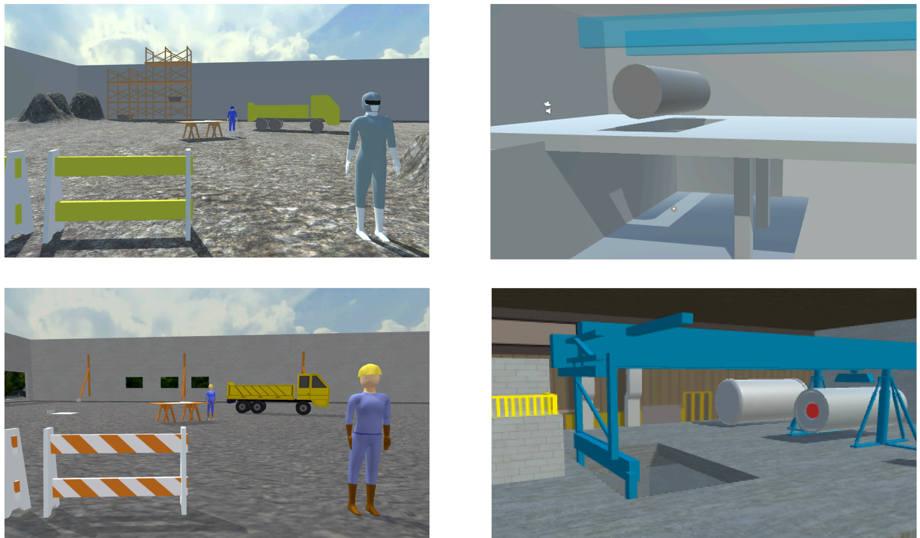

Figure 4.3: Visual Style Development

4.7 Development Tools

Upon creating a structure for the basic function of the application we started development. The assets were modelled using Autodesk Maya. We first created prototype environments to understand the areas and how the information should be distributed. At times this was difficult due to the limited amount of information regarding layout and scale. This was an iterative process. We would often find that we needed more assets to either fill the environment or explain a concept as we developed the interactions within the environment. In addition we would increase the complexity of the models and textures (Figure 4.3) as we shaped where we were going stylistically.

The interactive components of the virtual environment were developed in a gaming engine called Unity. There was a selection of standard assets that we used for character control and buttons, but many of the features were coded by our team. We started implementation for Case 01 keeping in mind how it would transfer to the second. This was our biggest challenge, making the code reusable and interactions applicable to both cases. Scripts were used both for in environment features and asset organization on the developer side.

After we completed around 75% of development for Case 01 we moved on to Case 02 to understand what was working and what had to change. This meant modifying the code we had written or creating new ones entirely. Throughout the process we took notes of our design choices with consideration to how the user might interact with the environment. We also obtained informal feedback to help guide our decision making.

4.8 Visual Aesthetic

A lot of effort went into getting the dimensions to match up in the first case (the partial masonry wall collapse) and this was mainly due to the quality of the drawings and the amount that was provided. The braces for example were explicitly marked as XxX size, the rebars at #5, the walls 25' wide, etc. With the amount of data we felt it necessary to make sure it was accurately presented. We looked up the real world dimensions of #5 braces, references, and standard construction guidelines to fill in the remaining information.

The necessity of dimension accuracy became less when dealing with the second case (the temporary overhead crane collapse). Hardly any information was given on the layout, or build of the crane other than a few drawings and many images. We were forced to focus on making the parts of the crane look right rather having it be to scale. Our rationale, a big looming crane is defined by it's overall appearance not individual parts. We treaded the line between plausible and accurate.

Overall, we modeled and textured the environment to look as much like the actual scene as possible, but chose a semi-stylized appearance knowing that we were limited on time and resources (Figure 4.4).

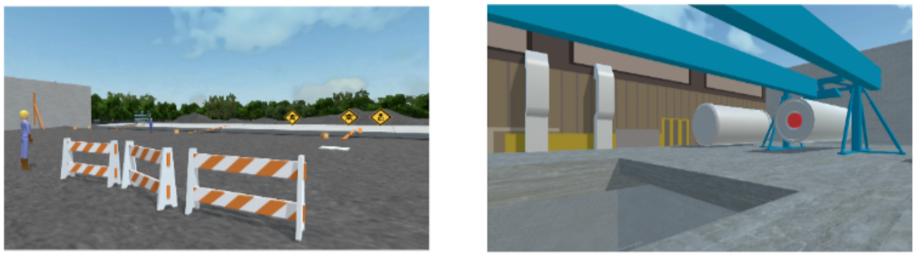

Figure 4.4: Stylized Visual Aesthetic (Left: Case 01, Right: Case 02)

4.9 Temporal Representation

The incident and correct procedure learning subjects were the most difficult to conceptualize, because they relied on changes in time. What we didn't like about the detective based learning, where the user would look at objects after the accident and then before, was that it didn't allow the user to freely select a time to look at. A few of our other ideas had similar downfalls. We decided to use discrete time steps to represent the look of the environment because it could be changed by the user however many times they desired. For Case 01 we ended up with three time steps; Noticing the Mistake, Brace Removal, and the Fallen Wall (Figure 4.5). Case 02 also had three time steps; Erecting the Crane, In Transit, and Collapsed Crane (Figure 4.6). To change the time within the construction site, the user could open up the menu and select one of the timesteps. Each time step would have a corresponding lesson of the incident event.

Changing the time within the construction project was not applicable to the correct procedure lessons since the time change happened within the lesson. For example in Case 02, learning about how to use the crane was independent of the time within the construction site. Still, we wanted the lesson to be taught in a sequential order to hint that the procedures take time. We also considered that each discrete time step was for a specific period in time that usually had smaller time increments within. Our solution to this was

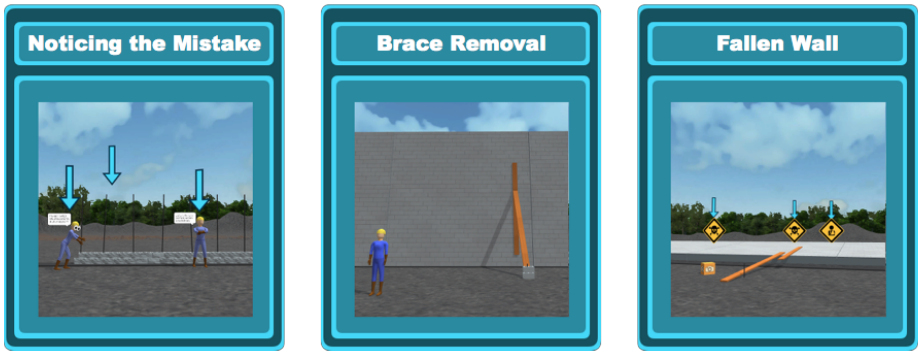

Figure 4.5: Case 01: Time Events

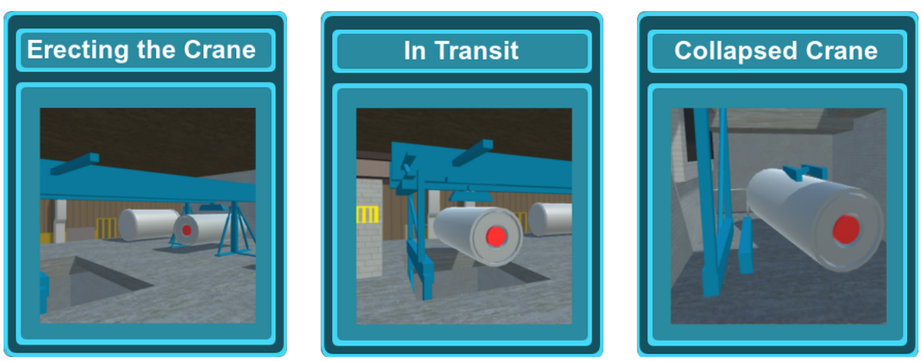

Figure 4.6: Case 02: Time Events

to create phases within the lessons to dictate which objects were interactive and / or not hidden. For example, in Case 01, Time 01 (Noticing the Mistake) the masonry contractor notices a mistake in the braces, tells the general contractor, the general contractor advises to continue construction by patching up the mistake, and the inspector does not report the error. Phase 01, would just show the masonry contractor noticing the mistake, once the user has finished learning about it, the general contractor would appear in Phase 02, and in Phase 03 the inspector would appear (Figure 4.7). When lessons were not being interacted with we created a default appearance which we called the Final Phase.

4.10 Information Representation

In this section we discuss the ways we represented the incident report data through space, visuals, text, and audio.

4.10.1 Spatial

Case 01 had a large open area, making it a challenge to encourage users to explore the entire environment. We decided to divide the environment into learning areas (Figure 4.8). A learning area was a physical location in the environment that either contained a lessons on correct procedures and the incident, or the table with documents and plans attached. This worked for Case 01, but was difficult to implement in Case 02 since it had two levels, both inside and smaller in size. To accommodate for this we allowed for fewer areas. In Case 02, that meant that the table accounted for one area and the remaining real estate the other. The greater challenge for Case 02 was creating the environment with no drawings of the layout, other than a isometric view supplied by the contractor. To overcome this we had to look up many reference images of the construction site and find as many details as possible in the text (Figure 4.9).

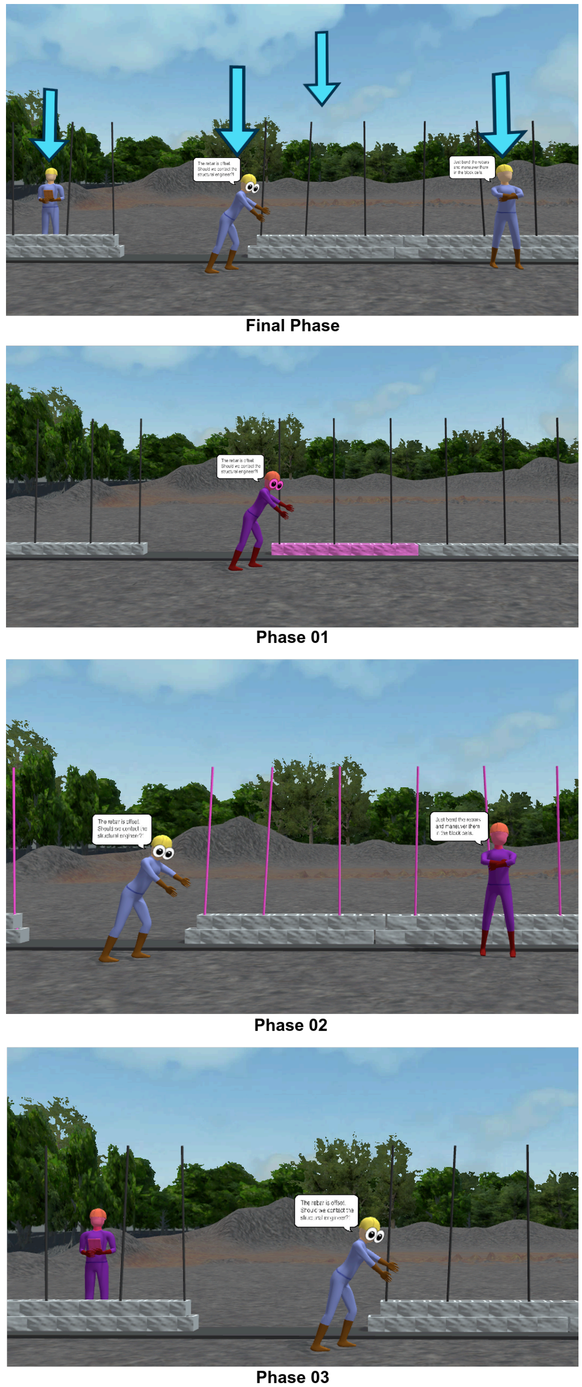

Figure 4.7: Phases within a Time Step for Case 01

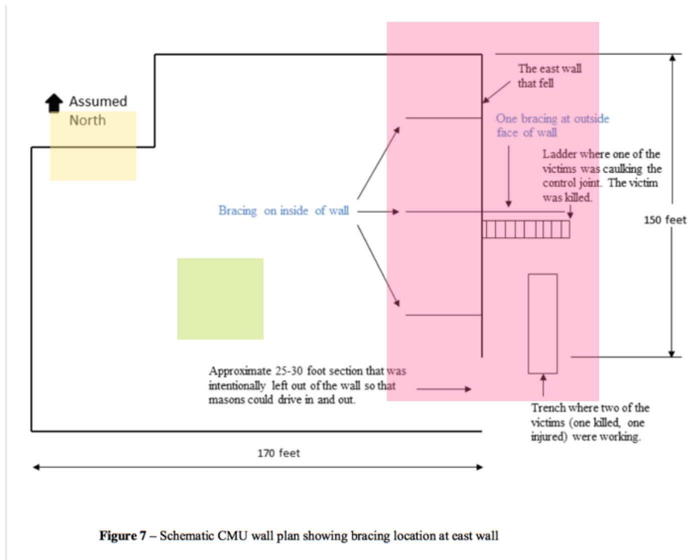

Figure 4.8: Case 01: Dividing the Area

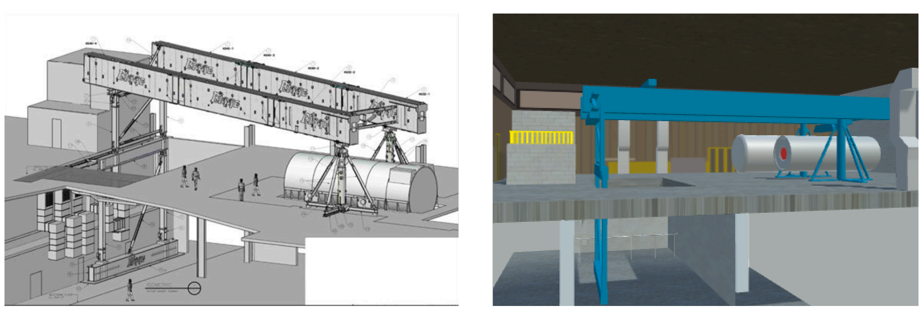

Figure 4.9: Case 02: Creating an Environment

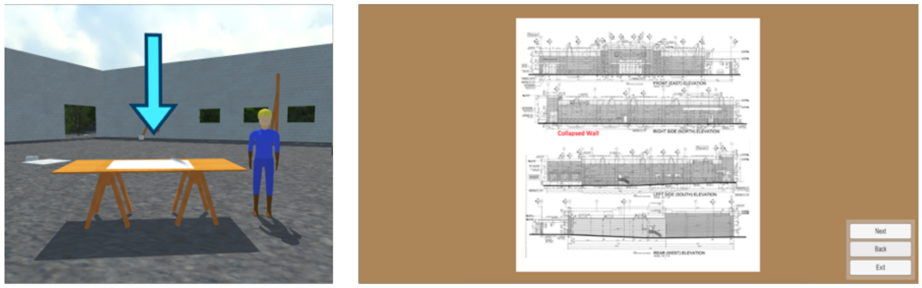

Figure 4.10: Documents and Plans Interface

4.10.2 Visual

We converted much of the information into a visual format through the environment. In an earlier section we talked about having semi-stylistic aesthetic and based our visual design decisions on it. We discuss how we created an interface for viewing documents and plans, included images from the incident reports, created people to populate the environment, and how we chose to represent death and injuries.

The documents and plans subject was conveyed via a screen overlay interface. To look at documents, drawings, and key personnel details the user had to approach the table, click on it, and a screen overlay of the information would appear (Figure 4.10). On the bottom right hand corner was a set of buttons to cycle through the documents and to exit the screen.

We wanted the user to feel a connection to what the construction scene and objects looked like in real life while keeping a stylistic aesthetic. We used the photos from the report and placed the images at locations corresponding to where they would have been taken in the environment. The photos were connected to a cube (Image Cube) that the user could click to toggle the visibility of the photo. All the image cubes for Case 01 were located on the ground due to the position of the camera. This was not so for Case 02, where some of the images were taken above human height (six feet in the VE) or referencing an

Figure 4.11: Design iterations for Construction Workers

object above.

We debated whether or not to include people. They were only mentioned in the incident reports when they were doing something incorrectly and even then, there was little to no details on their exact placement. Also, if we did include them we wondered if their lack of movement and/or detail would decrease immersion. We decided to keep them to add life to the environment, but had to spend time getting the right look. If each worker was unique, the lack of detail might be more apparent, requiring more realism. If they were all the same, having a realistic aesthetic would be more jarring. Figure 4.11 shows our iterations on the workers' appearance.

A difficult subject in the incident reports was worker injuries and deaths. We struggled with whether or not we should model it or symbolically represent it. We decided against showing the dead body because it would be hard to convey the gravity of the situation with simplistic models because it either wouldn't be taken seriously or end up overly gruesome. Choosing a symbol to represent death and injuries ended up having similar issues. Figure 4.12 shows the process we took to get the proper look for death and injuries. In our first iteration we created a simple emoji style person with a bandage to represent and injured

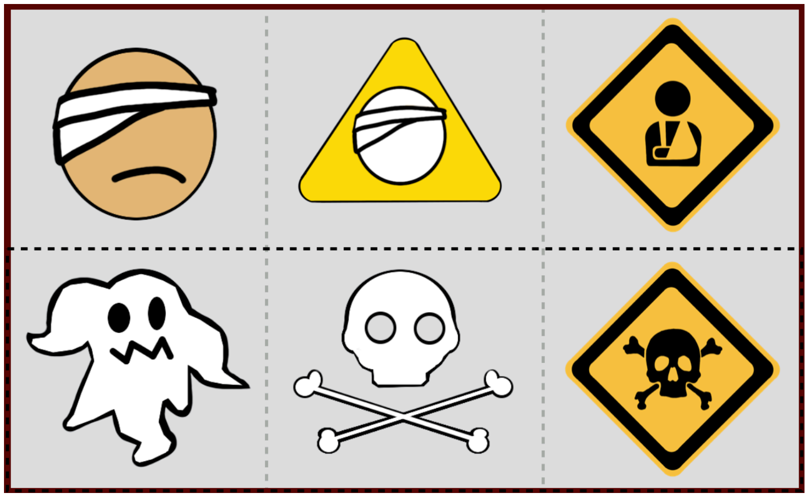

Figure 4.12: Design Iterations of Symbols Representing Death and Injuries

person and a ghost to represent death. Our informal feedback was that the icons were understandable, but came off as mocking. The middle icons was our attempt to make the them more cautionary. It was challenging, because there was no go-by for death and injury signs beyond warning symbols. For the final iteration we made the icons uniform in shape and style should we choose to add more types in the future.

4.10.3 Text

Each report included details regarding incident factors and the construction process that couldn't be dissemniate through visuals alone.

Our initial plan was to have the user approach the construction workers wearing dark blue suits. A dialogue box would then appear, asking them about what they would like to know. After a selection was made a dialogue box would be overlayed on the screen space asking the user to look around (Figure 4.13). When the user clicked an object the text would change. There were a few problems with this method. The identity of the person being talked to was unclear, more so when the user walked further away. It also put the user into the role of a person, which was not good in the second case where the user

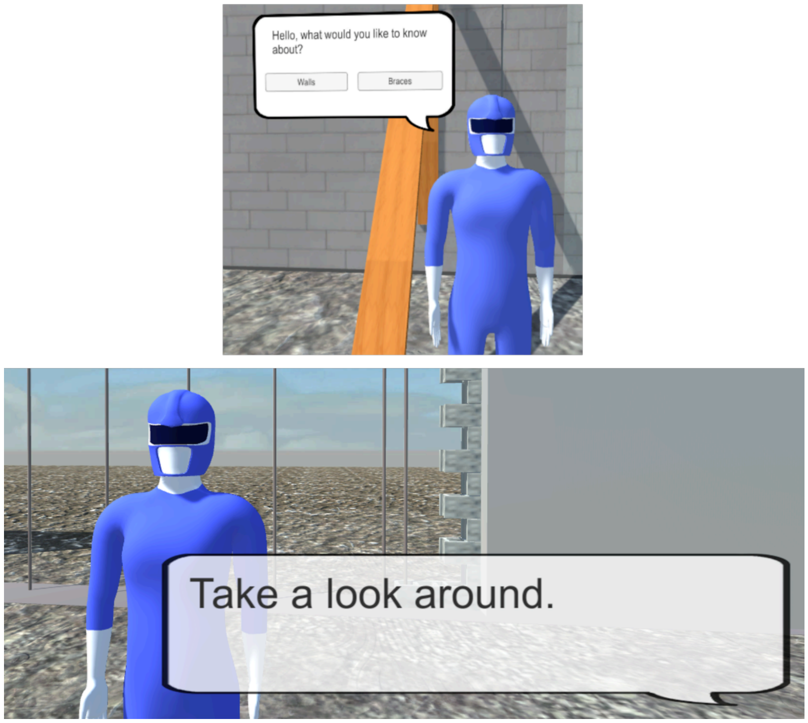

Figure 4.13: Information: Talking to Construction Workers

could move on the y-axis. Lastly, the interaction was not intuitive. The user would have to answer whether or not they wanted to change the lesson and then whether or not they wanted to learn the lesson.

While we removed the concept of talking to construction workers for information, we decided to add speech bubble planes to some of the people if applicable. Figure 4.14 shows the worker pointing out a mistake in the wall.

Billboarding is a technique where a 2D plane is always aimed toward the user. We considered billboarding and scaling a plane with information regarding the associated object. Figure 4.15 shows a plane with information regarding the wall. While it was interesting to look at, it became a bit jarring as it increased in size. It also didn't work well with smaller objects such as bricks.

We also experimented with dimensions overlaid on object by placing the width of the

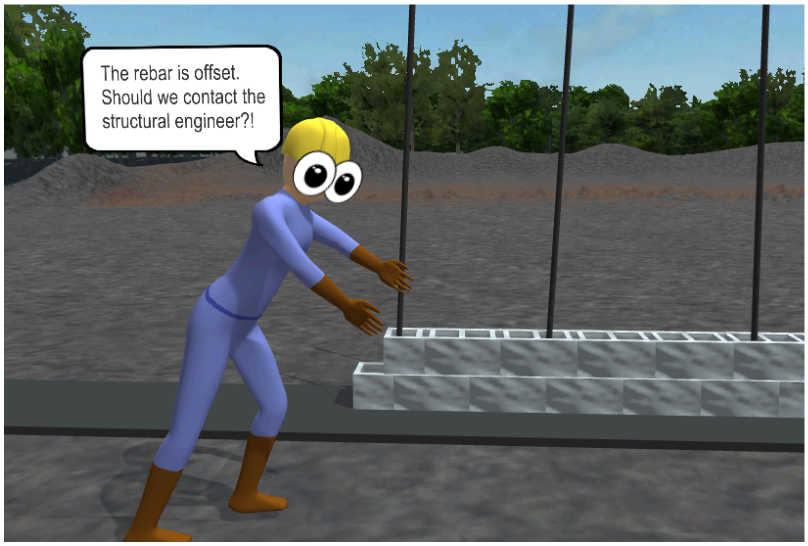

Figure 4.14: Information: Speech Bubble

Figure 4.15: Scalable Billboarding

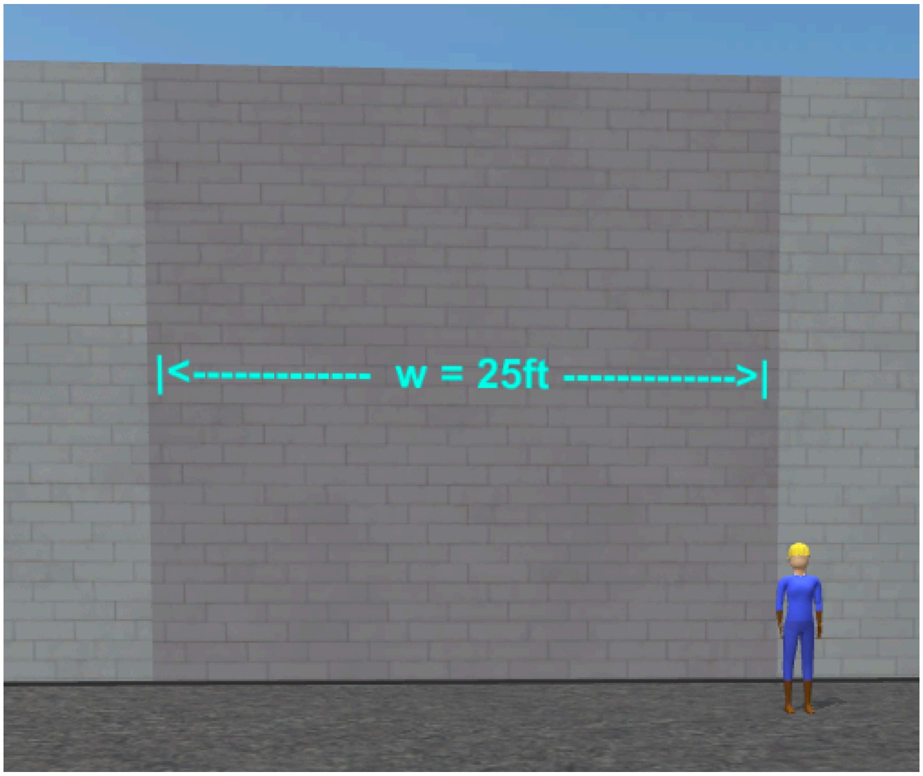

Figure 4.16: Graphic Dimensions

panel on a wall (Figure 4.16). We were interested in knowing if the user would understand the size of the wall due to the text rather than how it's size compared to the other objects in the environment. We weren't able to use this often due to readability.

To address readability issues and size constraints, we chose to overlay the information onto the screen (Figure 4.17). This allowed the users to read the information regardless of their position, giving them the choice to be near or far. The text appears on a information box rather than a speech bubble to make it clear that they are reviewing data and not communicating with the people in the environment.

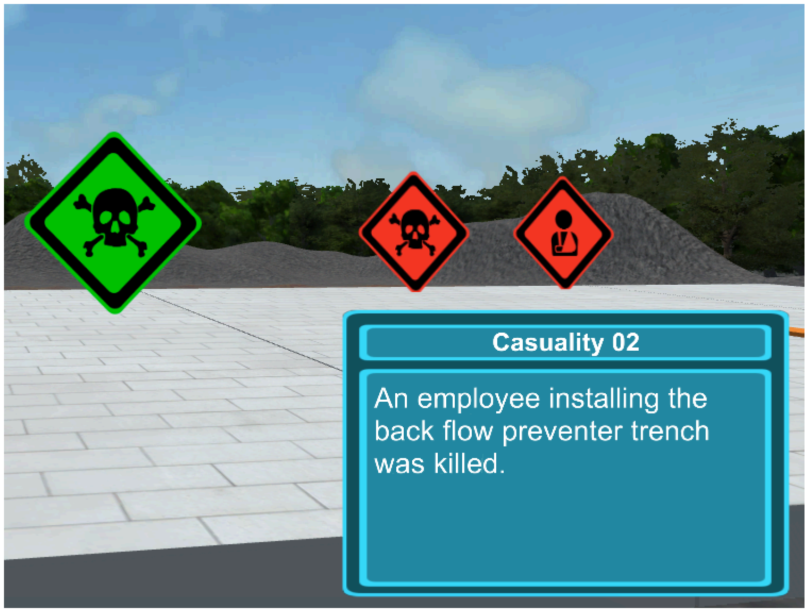

Figure 4.17: Information: Screen Overlay

4.10.4 Audio

We could have used a neutral voice to read the info so the user could focus on the environment, but we chose not to due to the lack of resources and time constraints. Also, there was no conclusive proof that it would fare better than text. Users could drown out the noise if not paying attention. Dialogue would have also been difficult for both cases since there weren't many direct quotes to read off of. Another option was to add noises to direct the users attention. For example, if the user was to approach an interactive item within the lesson they were currently engaged in, a slight ping could go off. Or if they walked away, the noise would lessen. A noise could have also been used should the user click something that not clickable. While users may feel more immersed with the ambient sounds of a construction site, having that noise would add an additional level of information that the user would have to parse through. In addition we would have to spend more resources coming with the right sounds. The only time we included audio was when it was part of the incident report. The report for Case 02 mentions an employee hearing a loud "pop like a gunshot" just before the crane collapsed

4.11 Interaction Techniques

In this section we discuss how the user interacts with the environment to learn more about the incident details and navigate.

4.11.1 Lessons and Phases

Lessons were used to convey the correct procedures and incident event information and required user interaction through phases. To proceed to the next phase and/or finish the lesson, the user had click all the objects within that phase. Clicking an item would select it, change it's color from red to green (Figure 4.18, and cause a dialogue box to appear on the bottom left corner of the screen with information regarding the selected item. We tinted the color of the object to inform the users that it could be selected or was selected. An issue with this was that the objects responded to the color tint differently (Figure 4.19). We also acknowledge that it is not ideal for anyone that is colorblind. To accommodate for this we added red circle markers to the mini map to show the object locations. We considered oscillating the size of the object but found that it wouldn't work on objects that are normally perceived as rigid (i.e. a wall). The ideal representation would be to make the object glow, but due to time restrictions and the development platform (Unity) it was out of the project scope.

4.11.2 Environment Navigation

It is important to consider how the user will get around the environment, because it impacts how things are placed. In a later chapter we discuss in greater detail how levels of interactive navigation effects learning by conducting a user study. This section pertains mainly to a higher level of interactive navigation, where the user has control of where they

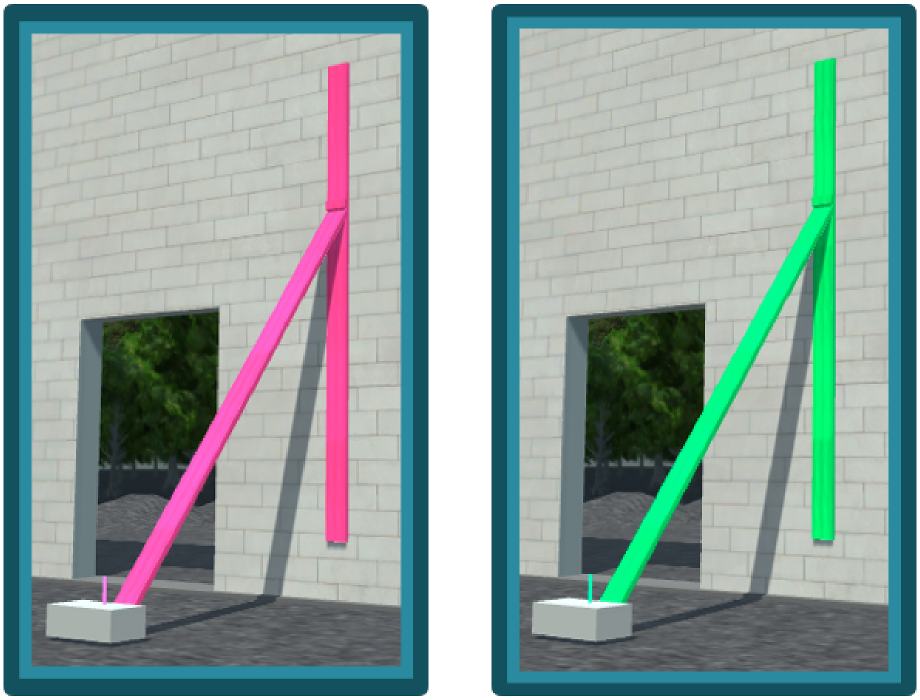

Figure 4.18: Example of an Object That Can Be Selected (Left) and Selected Object (Right)

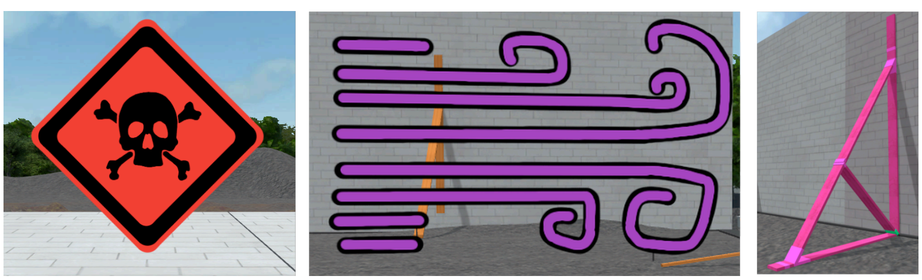

Figure 4.19: Examples of Varying Color Tint

can go and can learn the lessons at whatever order they desire. We must discuss some of these issues now when considering the accessibility of information. For example, an image cube located above the ground would be hard to get to if the user could only move in the x,z coordinate direction. Or, what happens when there is a large opening to the outside world behind the incident, should we limit the user's rotation?

In Case 01 a masonry wall collapsed on the ground level within the site area. We limited the the user to x,z translations and x,y,z rotations, because we were able to close off the area by lining it with trees. In Case 02 an overhead crane on the second level of a nuclear power plant collapsed onto the first level as it was being used to relocate an item from the second floor to the first for a shipment. To represent this we had to decided whether or not the user would have access to the ground level. By giving them access we had to consider the outside of the plant, that could be seen opposite of the collapsed crane. There was little information given on it and creating it would take additional time. Yet, if we constrained the user to the second story they would only have a aerial view of the item and less familiarity with the construction site (Figure 4.20). We compromised by allowing the user to access the ground level, but restricting their movement to a y,z plane and their rotation by 0°-180°. Doing this allowed the user to look at the bottom level without being able to turn around. We also allowed movement in the y-axis for items that were located above human height in the virtual environment. Figure 4.21) shows the axes of movement for each case.

In the applications the user navigates the environment egocentrically in Case 01 and mostly in Case 02.The benefit of this is that everything is to scale, providing a greater sense of immersion. The downside is that they will never truly be able to see the environment as a whole. For the second case we allowed movement in all directions, but it was never truly exocentric due to the constraints of being inside a power plant. With this taken into account, we created a minimap to show the user their position and orientation within the

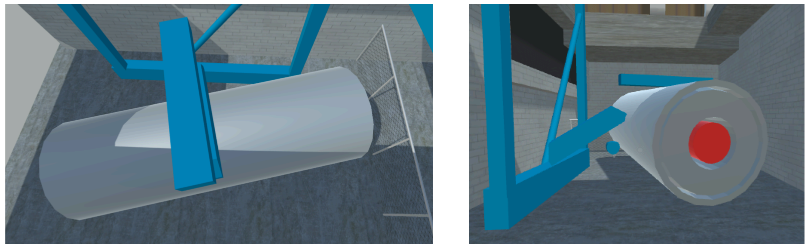

Figure 4.20: Case 02 Crane Collapse (Left: Top View, Right: Front View)

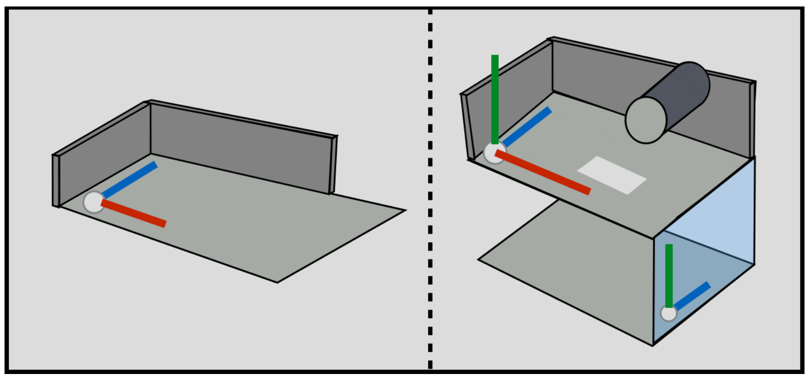

Figure 4.21: Environment Navigation (Left: Case 01, Right: Case 02)

environment (Figure 4.22). For Case 02 we added buttons to the right to toggle what level the user was on. We also included stars to represent the learning areas, image icons for the image cubes, and red dots for the items within the lessons (when engaged).

4.12 Informal Evaluation

Near the end of development we also conducted a few informal user studies on the application use. Participants had little comments regarding data representation and/or the visual aesthetic, though there was mixed feedback on the documents and plans viewer and changing the object color to make it known that it was selectable. Our main observations and feedback was in regards to the usability of the application. Participants were not sure where to go, didn't like having to open the menu to start a lesson, and did not like pressing

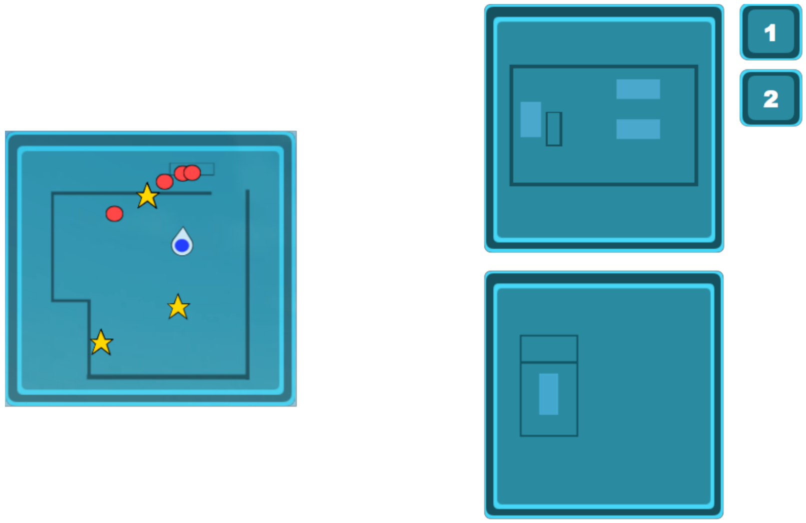

Figure 4.22: Environment Maps (Left: Case 01, Right: Case 02)

"B" to acknowledge they had read the text associated to the object.

From the feedback we made a few changes to the interface and interactions. We oscillated the size of the menu button for a few seconds upon the user entering an area with a lesson, the drafting table, or upon finishing a lesson to remind the participants of it's existence. Before, participants had to open the menu and click "Learn More" to start a lesson and often weren't sure if they were in the right area. Oscillating arrows were added above the objects associated to a lesson and the ability to double click them to start the lesson. We considered adding these arrows to each object for all phases, but felt that it would clutter the environment. The plans and documents viewer was kept to better understand if it was useful.

4.13 Conclusions of Case Study and Learning Outcomes

We designed and developed two applications to contextualize construction incident reports. The applications each consisted of interactive lessons on the incident report and correct procedures, and a interface to view documents and plans. We iteratively improved our design choices based on informal feedback and trial and error. From a few informal user studies it was clear that the effectiveness of the application relied on usability despite the amount of time that went into the visual aesthetics and information representation. If something was not intuitive, the user was less likely to pay attention to it. Our results support our rationale for conducting an experiment to understand how interaction techniques effect learning.

5. USABILITY STUDY: VIRTUAL REALITY APPLICATION

5.1 Summary

In the case study on application design we designed and developed two prototype applications, each based on a construction incident report. Going forward we will only be testing the first application that contextualizes the incident involving the partial collapse of a masonry wall. We explore the effects of the system device on usability by introducing a virtual reality version of the application. We discuss the transition from a desktop computer interface to virtual reality and the results from an informal usability study with five participants.

5.2 Goal

The purpose of this study is to develop a variation of the application using a HTC VIVE head mounted display and one controller as the system device to explore the differences in user experience and learning behaviour. It is important to consider the system device as it contributes to how the interactions are designed and how the information is represented. In the Case Study we developed the applications for use on a desktop computer system. It is unlikely that a participant would have had no exposure to computer applications and therefore would be more familiar with the system. Although fewer people have been exposed to virtual reality applications, research suggests that they can contribute to increased engagement and immersion. The challenges are the complexity of the controls and that users may feel distracted by the increased immersion.

For this study we will be using the application involving the partial collapse of a masonry wall to reduce the number of variables, limit the play area to one ground level, and assuming the construction of a store is more relatable then a crane being used in nuclear a power plant operation. We also discuss changes that have been made to address feedback from the Case Study.

5.3 Application Summary and Changes

The application to contextualize construction incident reports consisted of a virtual environment, system device, and interaction techniques. The one developed in the case study had three main learning subjects; the incident, correct procedures, and plans and documents. The incident and correct procedures were explained through interactive lessons. Plans and documents were images of plans or documents displayed via a screen overlay that could be accessed by clicking a virtual table in the environment.

5.4 Development of Virtual Reality Version

Changing the system device from a desktop computer, keyboard, and mouse to a head mounted display and controller required us to alter the application's user interface and brought along new travel techniques for the active level of navigational control. It also added additional usability issues such as changes in height and the time spent in VR.

5.4.1 Interface Changes

For the desktop computer version all textual information, the menu, documents and plans, and a mini-map of the environment was displayed as screen overlay. However, this was not possible in virtual reality because the information must be presented in a 3D space. The user interface was modified to accommodate the spatial change and access was mapped to the controller along with travel. One controller was used instead of two to prevent confusion with functionality. The textual information associated with the objects within the lesson was on a 2D plane attached just above the controller and aimed towards the participant (Figure 5.1) . The map was displayed via a heads up display and could be toggled on or off with by pressing the grip button. The menu was a 2D plane placed a few feet away from the participant in the direction that they were looking at when the menu

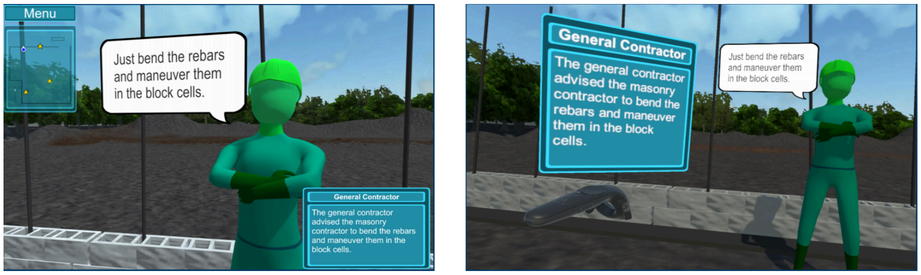

Figure 5.1: Desktop Interface to VR Interface

button was pressed (Figure 5.3). The equivalent of clicking with a mouse was pressing and releasing the trigger button. When pressed a ray would appear, starting from the controller and ending on whatever object or interface it intersected with. Releasing the button would complete the click.

5.4.2 Navigation

To navigate, the participant could either use the touchpad on the controller to move around in the x,z direction, trigger click a map to teleport to the desired location (Figure 5.2), or walk within a limited space in the physical world. The y position and x,y,z rotation of the camera was directly linked to the participants HMD. Participants were not limited to an area and could move wherever they wanted. They were not forced to learn the content in any particular order and could jump between the incident events, correct procedures, and plans and documents. Lessons could be initiated via the menu. They could also trigger click an object within the lesson (associated by an oscillating arrow) to bring up a heads up display asking them whether or not they wanted to start the lesson and then choose to start by pressing right on the touchpad. Exploration of the environment was based on the participant's choice. They could review the content without having to restart the application.

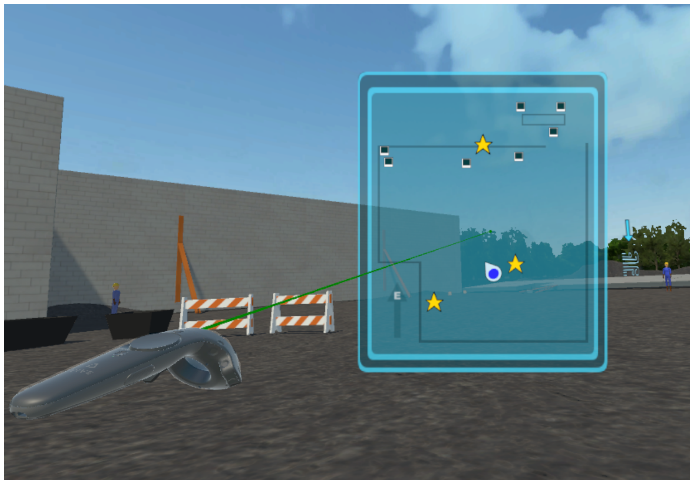

Figure 5.2: Environment Map in VR: User Trigger Clicking Map to Teleport to a Location

Figure 5.3: Menu in VR

5.5 Informal Evaluation and Results

We had five people use the application for 10-20 minutes and collected feedback from the participants and took notes on what we observed.

The major change in the user interface was the converting from a 2D screen overlay to 3D worldspace. 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 button was reassigned to acknowledge that the information had been read. We also observed that the user would open the map and forget to turn it off, or forget about it altogether.

Observations regarding the order participants chose to view the lessons using the active level of navigation control for the Desktop Computer system carried over to the VR system, but with one difference. Instead of finding and viewing image cubes participants were more interested in looking at the environment. One participant in particular, used the touchpad to move the play area forward while looking down at the bricks. Many users appreciated trigger clicking the map to warp to specific locations, but wanted more precise control. The touchpad could move the play area, but was often going past the desired location. This often resulted in the participant moving the play 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. In this variation the participants were asked if they would like to start a lesson if they trigger clicked a selectable items in the lesson. Most participant chose not to.

The textual information was placed just above the location of the controller and always aiming at the participant. We assumed that the participant would lift their arm to trigger the item and then keep it there to read the information. However, they would often lower their arm and look down at it.

Image cubes were looked at, but less frequently due to the trouble of precisely positioning the play area and participants unwillingness to physically position themselves.

The documents and plans table was far less effective in virtual reality, because the resolution was lower and it was displayed on a 2D plane always pointing towards the participant. The only way the user could view the document legibly was for them to physically move towards the plane, which we observed participants rarely did.

5.6 Discussion

Creating a new variation of the application representing Case 01 (The partial collapse of a masonry wall) for VR brought along new design challenges. The major change was in the interface. Before we were able to display all the information as a screen overlay, but could not do that in 3D space. From informal user studies we noticed that participants were eager to explore the environment, but often got distracted and didn't find all the information. Like the Case Study results, participants really focused on the usability of the application rather than the visual aesthetic. In future research we would like to consider different navigation types and text alternatives such as audio.

6. EXPERIMENT: HOW INTERACTIVE TECHNIQUES AFFECT KNOWLEDGE ACQUISITION

6.1 Summary

In our Case Study we designed and implemented two applications, each representing incident reports by containing a unique, explorable virtual environment with areas of interaction. This experiment was designed to study interaction techniques for knowledge acquisition regarding one of the two applications. We focused on the level of navigational control. In a IRB approved, controlled experiment participants explored the environment to learn more about the details of the incident report using one of three levels of interactive control for the desktop version. In the Directed version participants were given a semi-automated tour of the environment, the Active version allowed for full navigational control, and Guided was a blend of the Directed and Active versions. The experiment tested participant knowledge and comprehension regarding the incident through and collected feedback on usability and the information representation.

6.2 Goals

The purpose of this study was to understand the how user interaction in a VE representing a incident report effects learning. Previously we designed and developed two virtual environments for a desktop computer system with one level of navigational control. From informal pilot tests on the applications developed in the Case Study we observed that participants were unsure of where to go, if they had visited all the locations, and the order in which they should be learning the lessons. In this study we expand on interactive navigation by developing two new variations for Case 01 (The Partial Collapse of a Masonry Wall).

Results from this study can be applied to the second application, should we improve upon it in the future, due to the similarity in design. Case 01, the collapse of a masonry wall, was selected for two reasons. One, the incident occurred on one ground plane with a large area. Two, the participants may be more familiar with the construction of a wall than operations within a nuclear power plant.

High levels of interactive navigation can increase engagement and help cognitive learning and it is important to consider how much control the user has. Too much, and they might deviate from their primary task while trying to understand how to use the input controls [23]. If they aren't given enough control they won't feel engaged. In this study we developed two additional levels of interactive navigation with less control than the one developed in the case study and compared them through quantitative and qualitative analysis.

6.3 Hypothesis

We hypothesised that a middle level of interactive control would produce a higher performance score for the desktop application. We anticipated that giving the users freedom to select which items they would like to learn about yet limiting the area in which they could explore, would provide freedom of control without too much additional cognitive load.

6.4 Task

To test our hypotheses, we designed a task based on the learning areas in the virtual environment for Case 01 (the partial collapse of a masonry wall) to evaluate whether or not the information was being contextualized. Using Bloom's taxonomy as a guideline [24], we focused on knowledge and comprehension. The learning areas were over correct procedures, plans and documents, and the incident. Each had one or more lessons within. Examples of the information included are dimensions, factors that led to the incident, and dates.

Before exploring the construction site, participants spent at least five minutes in a tutorial environment to get familiar with the controls. When they were done, participants were told that they had up to twenty minutes to explore the construction incident environment, to learn as much as they could about the incident, and that they would be quizzed on the information gained. After the participant felt like they had explored the entire environment or the twenty minutes had passed they were given a paper test to assess their understanding of the information pertaining to the incident. The assessment covered information in the lessons and comprised of a total of 41 short answers, drawings, multiple choice, and multiple response questions. Participants were given at most twenty minutes to complete the test. Following the test, participants were given a System Usability Scale [25] questionnaire and experience questionnaire. These were used to understand how the participant felt towards the information representation in the environment and the complexity of controls.

6.5 Participants

Twenty-one university students participated in the experiment. Participants were distributed by those majoring in Construction Science and the other majors. By allowing students in other disciplines to participate we were able to determine whether the application was effective in delivering information to people who may not be as familiar with the material. We chose to limit participation to college students over 18 to maintain similar age experience. Participants were recruited via email and verbal announcement. There were eighteen male and three female participants.

6.6 Experimental Design

To test our hypotheses, we controlled the level of navigational control as one independent variable between subjects. Participants were assigned a variation of the application based on the level of navigational control. The participants were randomly assigned one of the three variations: Directed Control, in which the learner could only dictate the time of each transition between predefined points, Guided Control, in which the learner had to complete the lessons within a learning area to be transported to next, or Active Control, in which the learner could travel wherever they desired with no restrictions on the order in which they learned. The study was between subjects on the assumption that participants would memorize the answers and be more familiar with the environment if using the same application with a different variation.

The application included a virtual environment representing Case 01, the partial collapse of a masonry wall. There were three key learning subjects spaced throughout the virtual environment; correct procedures, plans and documents, and the incident events. The incident and correct procedures were conveyed through learning lessons. Each lesson consisted of phases. To proceed to the next phase the participant had to select and read information on every item associated to that phase. For example, if the participant was learning about how to properly build a wall, the first phase would talk about the base, the second about bricks and support, and the third about connecting adjacent wall sections. The documents and plans information was spatially located on a drafting table in the environment. We also included images that were attached to cubes that could be clicked to toggle them on or off. The image cubes were placed in the environment based on where the picture was taken in the real world environment and the time step that the participant was in.

6.6.1 Directed Control

The directed control was the lowest level of navigation control. The participant explored the environment through a semi-automated tour, proceeding by pressing "E" on the keyboard. The participant controlled the pacing and the x,y,z rotation of the camera, but not their location. The order in which they viewed the information was predetermined to remove decision making on where they should go next or whether or not they had ex-

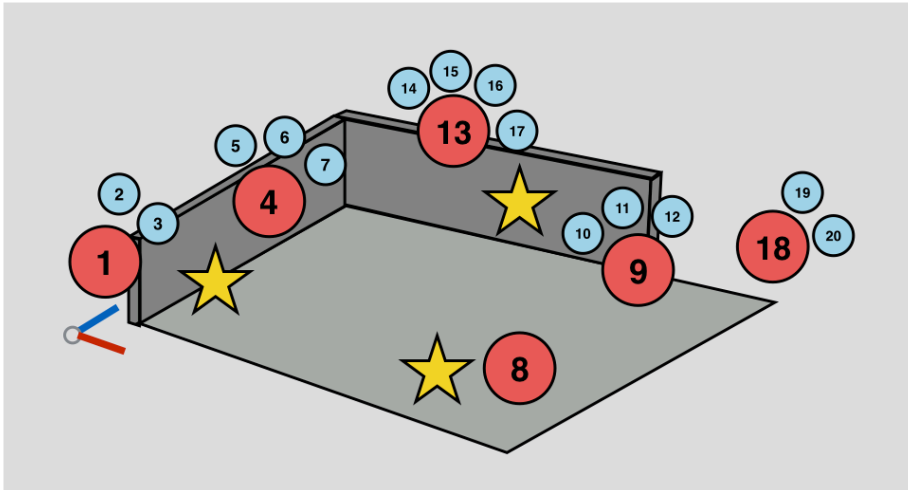

Figure 6.1: Directed Navigational Control

plored the entire environment. The participant was shown correct procedures, plans and documents, and lastly the incident. Image cubes were also ordered relative to the current time step. Figure 6.1 is a simplified example of the order in which the user was presented information. The full order of the content can be referenced in the appendix (Figure B.1). In this variation the user explored the environment linearly and could only go forward. The application could be restarted should the participant request to view it again.

6.6.2 Guided Control

Guided control had more control then directed, but was still limited. The participant explored the environment by clicking the mouse and dragging it to change the x,y,z camera rotation, using "W","A","S","D" to move the camera in the x,z direction, and pressing "E" to acknowledge that the information had been read. The virtual environment was divided into three learning areas with lessons and information associated to each. The participant could not leave the learning area until all of the lessons were viewed or the documents and plans table was viewed. Lessons could be initiated via the menu or double clicking objects

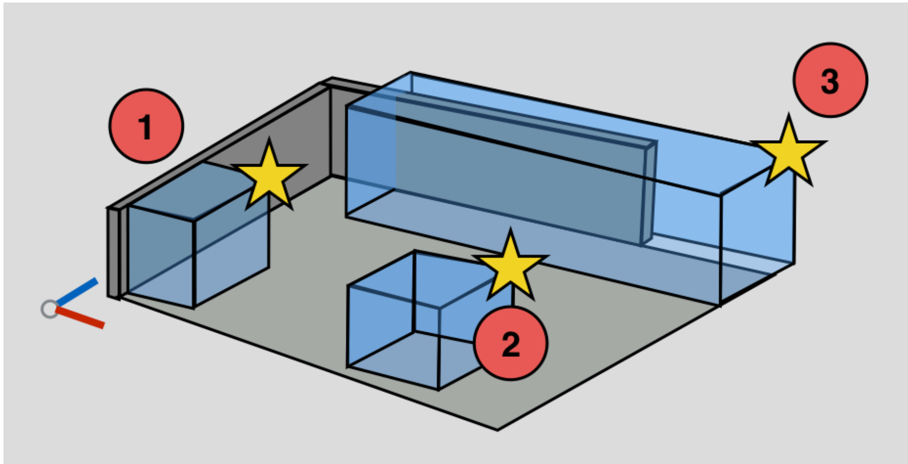

Figure 6.2: Guided Navigational Control

within the lesson (associated by an oscillating arrow). Figure 6.2 shows the environment simplified and the blue boxes represent each learning area. The participant was warped to the next area upon completion. Viewing the image cubes was not mandatory. Like directed control, the user could only go forward when warping to learning areas. The application could be restarted should the participant request to view it again.

6.6.3 Active Control

The highest level of navigation control is Active control (Figure 6.3). The participant explored the environment by clicking the mouse and dragging it to change the x,y,z camera rotation, using "W", "A", "S", "D" to move the camera in the x and z directions, and pressing "E" to acknowledge that the information had been read. Participants were not limited to an area and could move wherever they wanted. They were not forced to learn the content in any particular order and could jump between the incident events, correct procedures, and plans and documents. Lessons could be initiated via the menu or double clicking objects within the lesson (associated by an oscillating arrow). The mini-map located on the left-hand corner of the screen (available to all variations) had star markers

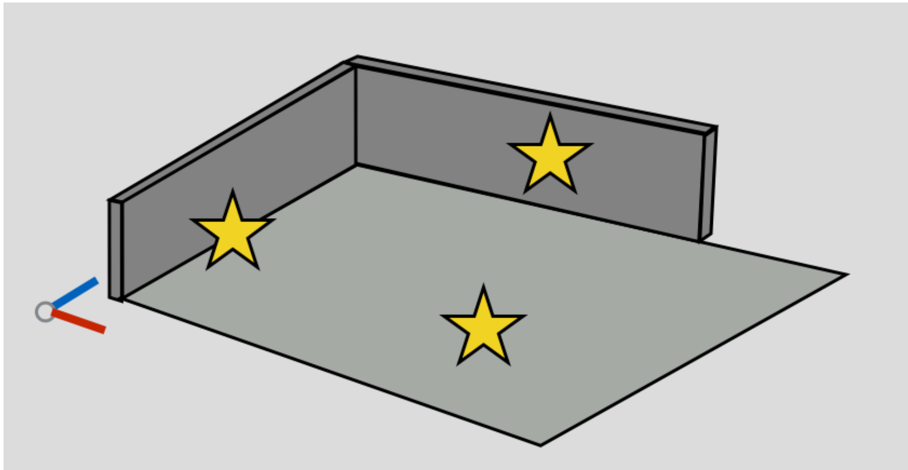

Figure 6.3: Active Navigational Control

to represent the learning areas, subtlety hinting participants that they should visit that area. Exploration of the environment was based on the participant's choice. They could review the content without having to restart the application.

6.7 Procedure

Participants were first presented with a paper printout with informed consent information. The experimenter explained the consent information and asked the participant to read over the form and sign it. Following, the participant completed a background questionnaire about basic demographics, computer visualization, experience with virtual reality, computer games, and their construction safety experience.

Some variations of the application required more explanation and familiarity with travel and environment interaction. For this reason, the participant were required to spend at least five minutes using a tutorial application to explore a virtual environment with the level of navigation control they were assigned. The application was designed to include learning areas similar to the application for Case 01, but with different content. The learning areas were over how to correctly build a snowman, plans and documents related to snowmen, and timesteps showing their life cycle. We chose to base the content on snowmen to shift the focus to the controls.

After the participant was familiarized with navigating the environment they were asked to read the following :

“A Goodwill Retail Store began construction early March 2013. During construction, on April 18, 2013, the wall collapsed. Two employees were killed and one was injured. The Occupational Health and Safety Administration (OSHA) investigated the accident to determine the cause(s). Please explore the environment to learn about the proper construction safety standards for masonry walls, look at documents involved in the case, and what happened at different points of construction.”

The experimenter explained to the participant that they would be given twenty minutes to explore the environment and would be quizzed on it afterwards. The participant began the application with the option to stop if they felt that they were ready to take the test. If the participant finished they were given the option to restart the application.

Immediately after the participant finished using the application they were presented a paper quiz on information found within the environment. They were told that they had at most twenty minutes to complete it and could finish anytime before. The experimenter than asked the participant to complete a questionnaire to collect information on usability and experience. A brief interview was conducted after to give the participant a chance to elaborate on their experience. The entire session took no more than 90 minutes.

Experiment documents are included in the appendix. In the following chapter we present the data and analysis.

7. DATA COLLECTION AND ANALYSIS

In the experiment participants were asked to fill out a background, usability, and experience questionnaire, and take a quiz based on information found in the application for Case 01 (partial collapse of a masonry wall). In this chapter we go over how the data was collected and analyzed.

7.1 Quantitative Data

Immediately after the participant finished exploring the virtual environment they were asked to complete a 41 question quiz comprised of short answer, drawing, multiple choice, and multiple answer questions. The quiz was in a paper format (Figure B.2). Participants were given twenty minutes, but allowed to turn it in before then. The quiz was designed to test comprehension and knowledge from Bloom's Taxonomy [24]. Participants were also asked to complete the system usability scale questionnaire. The scale gives a quick global understanding on the usability of the system [25].

Quantitative data taken from the incident report quiz and usability scale and analyzed using Analysis of Variance (ANOVA). We analyzed the participants time spent using the application, knowledge and comprehension of the incident, layout understanding, and application usability. For each we checked if ANOVA's assumptions (homogeneity of variances and normal distribution) we met by visually comparing the variances and distributions.

7.1.1 Time Using Application

Each participant was given at most 20 minutes to explore the environment but could choose to finish should they feel that they have explored everything. Participants in the directed and guided levels of navigational control were more likely to finish early due to

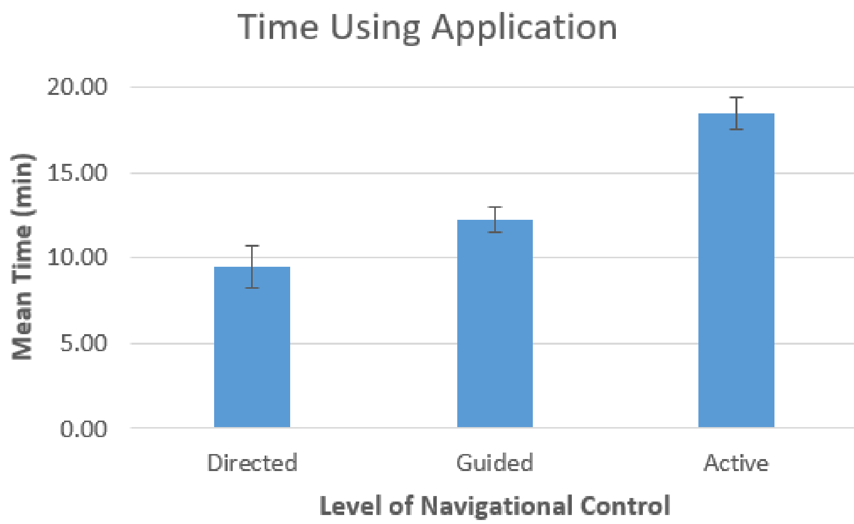

Figure 7.1: Mean Time Spent Using Application by Navigational Control (Error Bars Defined By Standard Error)

the linearity of the application and, in the case of directed, easier controls. The analysis for the time spent using the application supported this by showing a significant main effect of level of navigational control on the time spent using the application, with $F(2, 16) = 17.590$ and $p < 0.005$. We used a a post-hoc t-test to understand how the time varied by levels of navigational control. We found that there was a significant difference between directed and active ($t = 5.22$ and $p < 0.05$) and directed and guided ($t = 4.83$ and $p < 0.05$). There was no significant difference between active and guided. Figure 7.1 is the mean time spent using the application based on the level of navigational control.

7.1.2 Comprehension

The first eight short answer questions were used to determine if the participant understood the basic details of the incident. For Case 01 the incident happened for multiple reasons; the structural support was incorrectly placed, the boss told the workers to bend them into place, and bracing to hold up the walls were inadequately installed, designed,

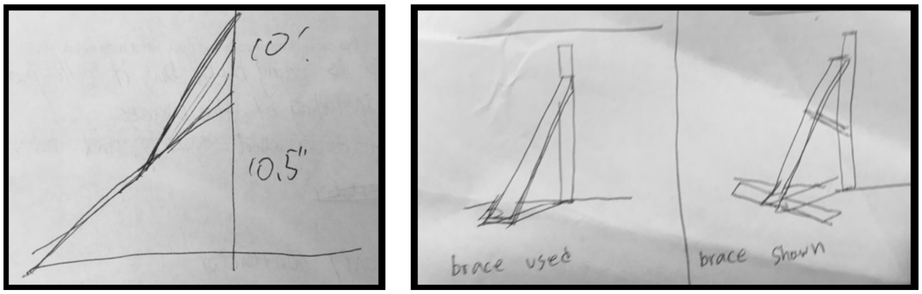

Figure 7.2: Participant Depictions of Braces Found in Environment

and removed prematurely. Scoring of these questions was on a scale from zero to ten and based on a rubric. (Figure B.6).

In the application the participants were shown how to install a brace properly and how it was actually built on the site. Participants were asked to draw the different braces to test whether or not they understood the right on wrong way to install the braces. About four responses included both braces. Of those, few were able to depict the braces accurately (Figure 7.2).

The comprehension score was an accumulation of the first eight short answer questions and the participant's ability to recall the brace types. There was no significant statistical difference in the means, with $F(2,16) = 0.450$ and $p = 0.634$. Figure 7.3 shows the mean scores of the participants categorized by the level of navigational control.

7.1.3 Knowledge

The remaining questions were used to test the knowledge gained by the participants and mostly consisted of supplemental information conveyed textually. Two questions were not used in the analysis, because the answer was not included in the environment information. Answers to the questions were conveyed textually (i.e. text explaining that 6 braces were installed) and visually (i.e. noticing the number of braces installed). There was no significant statistical difference in the means, with $F(2,16) = 0.469$ and $p = 0.634$. Figure

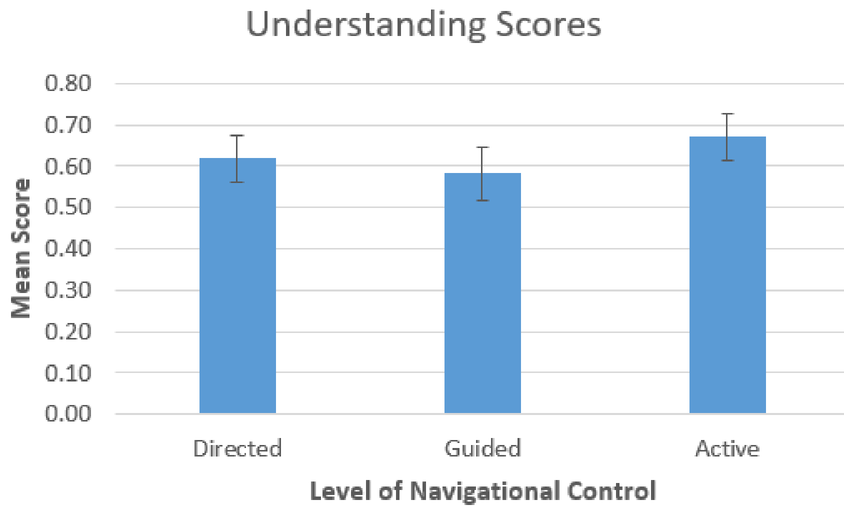

Figure 7.3: Mean Scores for Comprehension (Error Bars Defined by Standard Error)

7.4 shows the mean scores for knowledge distributed by the level of navigational control.

7.1.4 Layout Understanding

Participants were asked to draw the site layout to test if they understood the different areas of the environment and if it correlated to how the participant traveled. All participants were able to draw a rectangular shape, four participants depicted the true shape (7.5). While it was not asked, some participants included a compass and the layout of information. While reviewing the responses we noticed that some were drawing the site based on a document included in the plans and document table (Figure 4.8. It was unclear if the response was influenced by the document or the level of navigation control. There was no significant statistical difference in the means, with $F(2,16) = 1.477$ and $p = 0.256$. Figure 7.6 shows the mean scoring of the drawings based on the level of navigational control. Scoring rubrics can be found in the Appendix.

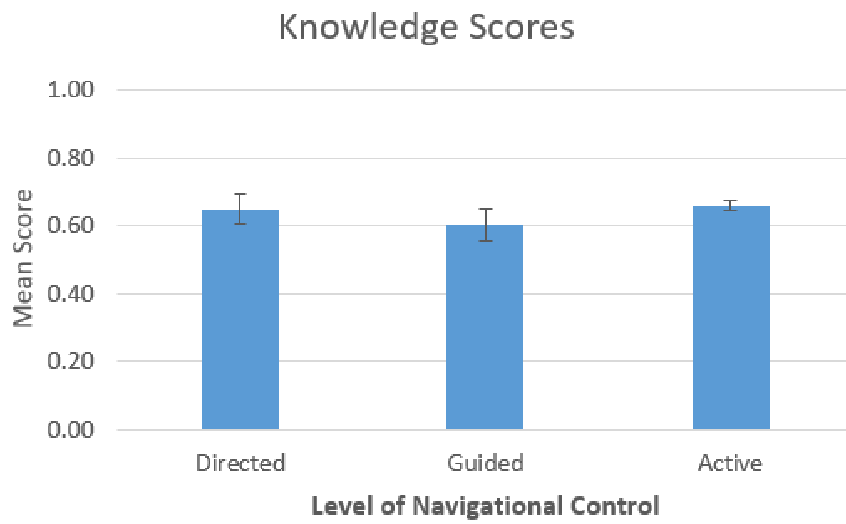

Figure 7.4: Mean Scores of Participant Knowledge Distributed by Navigational Control

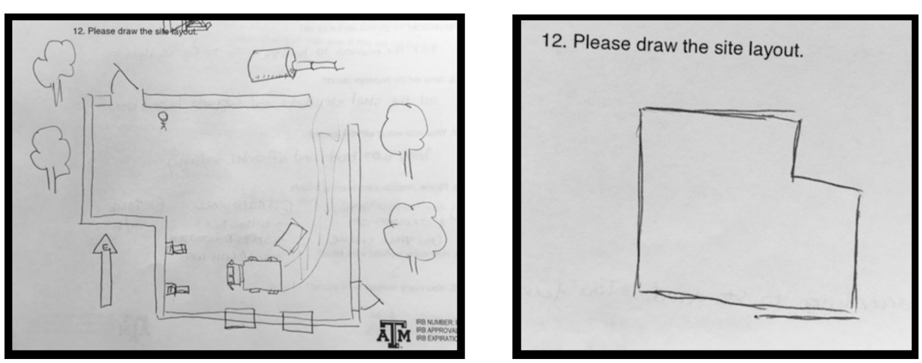

Figure 7.5: Participant Depictions of Environment Layout

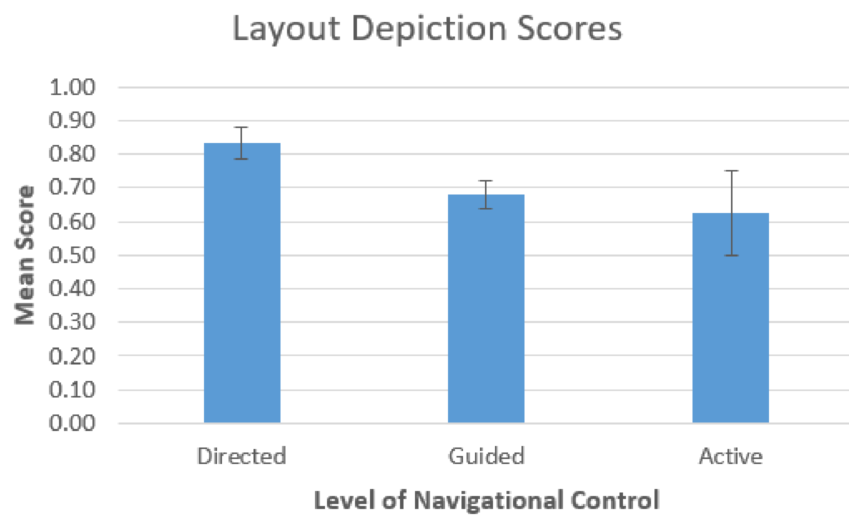

Figure 7.6: Mean Scoring for Layout Depictions Distributed by Navigational Control

7.1.5 Usability Questionnaire

Upon completing the quiz, the participant was asked to complete the systems usability scale (SUS) questionnaire through an online form. The SUS is commonly used industry standard to test the usability of systems such as hardware, consumer software, and websites [25]. The questionnaire consists of ten questions ranging from one to five. Odd answers were scored by having one subtracted from the response, even responses were subtracted from five. The converted responses were then totaled and multiplied by 2.5, resulting in a range from zero to a hundred. There was no significant statistical difference in the means, with $F(2,16) = 0.702$ and $p = 0.510$. Figure 7.7 shows the mean usability scores based on level of navigational control.

7.2 Qualitative Data

Qualitative data was collected via observations from the experimenter, responses in the experience questionnaire, and a brief interview with the participant. The data was used

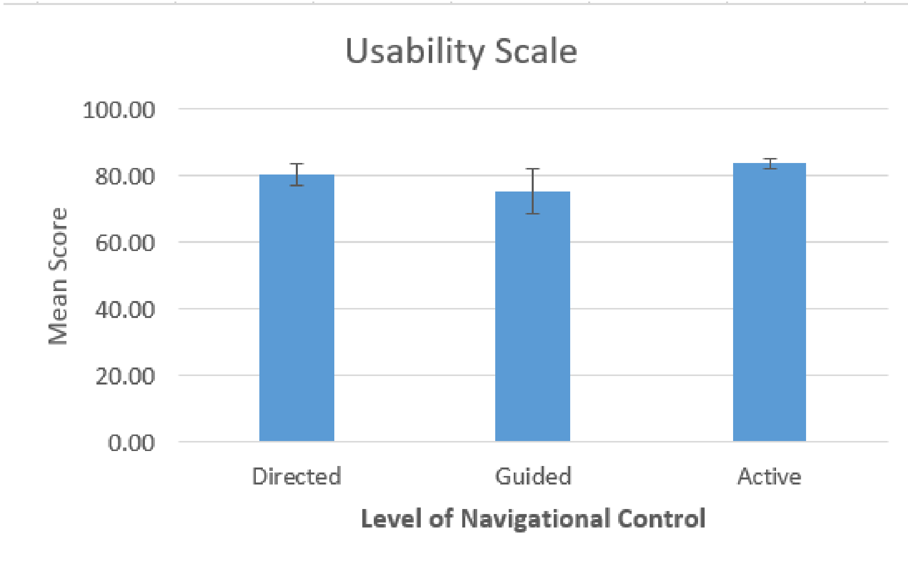

Figure 7.7: Mean Scores of Usability Scale Distributed by Navigational Control

to understand how the participants strategies varied by level of navigational control and additional feedback on the representation of the incident details in the virtual environment.

7.2.1 Viewing and Navigation Strategies

The experimenter took notes on how the participant interacted with the environment and the order of which they explored the learning areas.

For the directed level of navigation control for the Desktop Computer system the participant was control the pacing for information acquisition and camera rotation. The information was presented in a predetermined order. Participants finished the application in an average of 9.50 minutes out of the given 20 minutes. No one asked to re-view the information from the beginning, though they were given a choice. However, some participants recommended having a way to go back to the previous information location. We observed that most people using this variation did not rotate the camera beyond the first two stopping points. A few participants expressed that they could not understand where they were in the environment and wished to look at it from a broader perspective.

The guided level of navigation control for the Desktop Computer system restricted the user to a learning area. Once all the lessons and information in the area was looked at, the participant was warped to a new area location. Many people showed confusion when they could not leave the area and were stopped by an invisible barrier, despite encountering it in the the tutorial and being told that they could not leave the learning area until they finished viewing the information in the tutorial. We observed that this variation indirectly and unintentionally gave the participant an objective to complete each area, though the main objective was to learn about the factors and details regarding the incident. One participant asked to repeat the lesson.

The active level of navigation control for the Desktop Computer system was the highest level of control, giving the participant the freedom to move around on the x,z plane and x,y,z camera rotation. With this freedom came confusion on where to go, what to do, and the order in which to learn things. Most participants started by heading to the fallen wall, because it was where the camera was facing at the start of the application. After, they would either head to the plans and documents table, or the proper procedures area. Once all areas were visited some would inquire if they had completed everything. One participant referred to the areas as a "level". Sometime participants would seek out all the image cubes, not recalling that they could use the menu to change time steps or lessons. When they did remember, some participants were unclear on what time steps they had learned about when selecting them through the menu. Also, they showed displeasure when accidentally repeating the lesson through double clicking. From interviewing participants, we noted that many just wanted a hint or a marker to show what lessons or information had already been viewed.

7.2.2 Application Feedback for the Desktop Computer

The initial design of the application representing Case 01 (the partial collapse of a masonry wall) was made in our Case Study alongside a second application representing Case 02 (the collapse of a temporary overhead crane). Observing the users interactions with the items within the scene, user interface, and time steps was beneficial in learning what representations and interactions were effective for the desktop computer system.

We observed that the image cubes were a hit or miss in terms of participants seeking them out and turning them on. Participants were forced to view them in the directed level, but wouldn't spend more than a few seconds looking at them. In the guided version, participants were so focused on finding and viewing the lessons to proceed, that they didn't bother to seek them out. Image cubes were most purposely viewed in the active level, most likely because they were the easy to locate and interact with when the users didn't know what to do.

The documents and plans table was also a hit or miss. Some people (mainly the Construction Science majors) enjoyed reviewing the plans and others skimmed over them. The documents that contained a lot of text were unappealing. Some participants in the guided and directed variations desired to go back to the table and review them to get a better overview of the environment as they learned more.

There was little to no negative feedback on the visual aesthetics of the environment. The participants were okay with the stylized depiction. Participants rarely approached items for a closer look, they mainly focused on the textual information. Some didn't even notice the phase changes. For the lesson on the construction workers noticing the mistake, no one pointed out that the structural supports were placed incorrectly in the environment nor that they were bent in the next phase. Some participants suggested that we include a clear side by side comparison of the correct and wrong construction procedures.

The menu was not apparent to users despite being shown it in the tutorial and having it oscillate in size upon entering a learning area or completing a lesson. The menu was primarily used to change the time step and lessons in a learning area. Only one of the participants looked at the other tabs, including one that went over the input controls and what could be found in the environment.

Similarly the mini-map was not often looked at. It was located on the top left-hand corner of the environment and showed the locations of learning areas and objects within a lesson. We noted this when participants kept asking for the locations of the selectable objects or walked away from the area completely, not noticing the circular markers symbolizing the objects.

7.3 Discussion

In the experiment chapter of this report we hypothesized that the middle level of interactive control would produce the best results because it gave the participants structure in the order of learning, but still allowed them full control of movement. Because there was no statistical difference in the knowledge and comprehension scores, we could not conclusively answer the hypothesis. It is worth noting that the guided level of navigation got the lowest mean score for both knowledge and comprehension.

There was a statistical difference in the time spent using the application. It is understandable that it would take more time for the participant to explore the environment if they had to get comfortable with the controls and figure out where they should be exploring. This is interesting when comparing it to the statistically similar mean scores for knowledge and comprehension. This could mean that it would be beneficial to direct the participant around the environment if the learning goal is knowledge and comprehension, because it took the least amount of time.

From development we wanted the application to be an exploratory tool to learn more about the incident described in the report. By telling the participants that they would be quizzed on the information the new objective indirectly changed to finding all the information and memorizing it. We also noted that the behaviour of the participant was influenced by the level of navigational control. If in the directed group participants didn't care to look around, they just wanted to receive the info. The guided group was concerned about finishing each section, not considering the environment as a whole. The active group did explore more, but mainly out of confusion rather than curiousity.

We suspect that if we took recall over a period of time into account the scores may have produced a better spread. In the future we would like to invite participants to come to a second session to see if they can recall the information. We would also like to come up with a better metric for understanding what data representations are working more than others. For example, the plans and documents table may not be necessary.

8. DESIGN GUIDELINES

In this chapter we discuss our design guidelines for an interactive application that contextualizes a construction incident report using a virtual environment, system device, and interactive techniques. These guidelines were created from the results of our Case Study (Contextualizing Construction Incident Reports) and the data collected from our Experiment (How Interactive Techniques Affect Knowledge Acquisition).

8.1 Data Preparation

Before developing the application to contextualize construction incident reports, it is necessary to understand what information is being contextualized. As it is, the paper cannot be visualized word for word. We suggest first understanding the factors leading up to the accident, categorizing the report information, and then forming it into data that can be conveyed in the virtual environment.

In our Case Study we looked at two different incident reports; Case 01 and Case 02. In Case 01, a masonry wall collapsed and caused two deaths and one injury. In Case 02, a temporary overhead crane being used in a a nuclear power plant collapsed and caused one death and eight injuries. It was important that we understood what caused the accident by looking at the key participants, event factors, and the timeline of the incident. We used Suraji's accident causation model to categorize the incident event factors. Alternative approaches can be used. The goal is to systematically define the essential information.

We then categorized the report into Essential, Supplemental, Environment, and Misc. details. For example, in Case 01, it was essential that we knew the structural supports were bent and supplemental to know that the walls were grouted using a low lifting method. While it isn't necessary to use these exact categories, we suggest understanding what needs to be taught and what will contribute to the look and feel of the environment.

8.2 Defining Learning Objectives and Storyboarding

After understanding what data is available and the role it plays, we suggest looking at the learning objectives. Knowing what you want the user to learn helps in designing information accessibility. If this is not done, there is a risk of having to modify or rewrite the application's functions, thus wasting time in development. We encountered this issue in our case study when development started with the application having game like features and figuring out what exactly we wanted the participants to after some implementation. When we migrated to a more exploratory learning environment some of the code was no longer necessary.

For us, having the participant explore the environment under the guise of a detective and answering questions at the virtual environment before the incident was not helpful in understanding the contextualization of the report. Bloom's taxonomy was helpful in forming the learning objectives [24]. In our case we were concerned about comprehension and knowledge and therefore found it useful to make the application a learning tool. If we wanted the participants to analyze or create things, a serious game might have been more beneficial However this isn't to say that certain learning types aren't suitable for games. It all depends. Sandham looked into learning taxonomies and gaming mechanisms and found that knowing the learning objective is not enough. There is still room for .... should also consider the user [26].

8.3 Choosing a System Device

The system device that is used to execute the application is important for deciding how the user will interact with environment and navigation because it sets constraints via the input controls. For our guidelines the system device is all the components that goes into the system. Different systems devices can increase immersion, but can also hinder the participant if they are not familiar with the controls. The application is less useful if extra effort and time is needed to learn new skills for using it [12]. There are many options to choose from, but we will only discuss the desktop computer, mouse, and keyboard and a HTC Vice Head Mounted Display and one controller since we developed an application for each.

The desktop computer system was useful because of its familiarity, resolution, and ability to use screen overlays. Many participants picked up the controls quickly. The screen overlay option was nice for letting the participants have the text appear at the same location. There was little to no limit on the resolution of text and textures. However, system familiarity was also a negative. A few participants expected the controls to work a certain way and were slightly disoriented when it did not. Also, participants were used to computer applications making our application less unique. The VR system was useful for increased immersion and allowing users to intuitively get a closer look at objects. From the usability study we noted that a few users would bend over to get a better view of objects at a lower height. This also meant that participants were more interested in looking around and exploring then learning about the incident. Some participants expected more realism when walking around, comparing their experience to more commercialized VR applications. The application did take more adjustment time for participants to become familiar with the controls.

Choosing a system device should be based on the functionality of the application and usability. For an informational tool, such as ours, we suggest using a desktop based application. However, should the resolution of VR improve, participants familiarity with the system increase, or the function of the application require more interactions, VR could also be a viable canididate.

Figure 8.1: System Device: VR and Desktop Computer

8.4 Visual Aesthetic

In this section we discuss simplified, stylized, and realistic visual styles that can be used for the visual aesthetic of the application. We base our list of visual styles on the Taxonomy of CG Techniques that was discussed in Tim et al. paper on visual style development for serious gaming [27].

8.4.1 Simplified

In this style the objects are low in detail and often symbolic in form. The surfaces and lighting are flat. We found that symbols were useful for representing subjects that were difficult to approach. In our case study we used this style for representing death and injuries.

8.4.2 Stylized

In this style the objects detail ranges from low to high and may have some unrealistic proportions. The surfaces and lighting of the objects are basic shading and texturing. If there is little information provided by the incident report on environment details, this style is useful. Participants will recognize the object, but not question that it isn't dimensionally accurate.

8.4.3 Realistic

In this style the objects have a high level of details and are photo accurate. The surfaces and lighting of the objects are also photo-realistic. Should the incident reports begin to include Building Information Models to give an accurate representation of the site, this style would probably be feasible. However, as it is, photorealism is hard to achieve without lots of reference.

Tim et. al discuss that the visual style may be influenced by the learning goal. In our case study we observed that participants didn't really care about the complexity of the

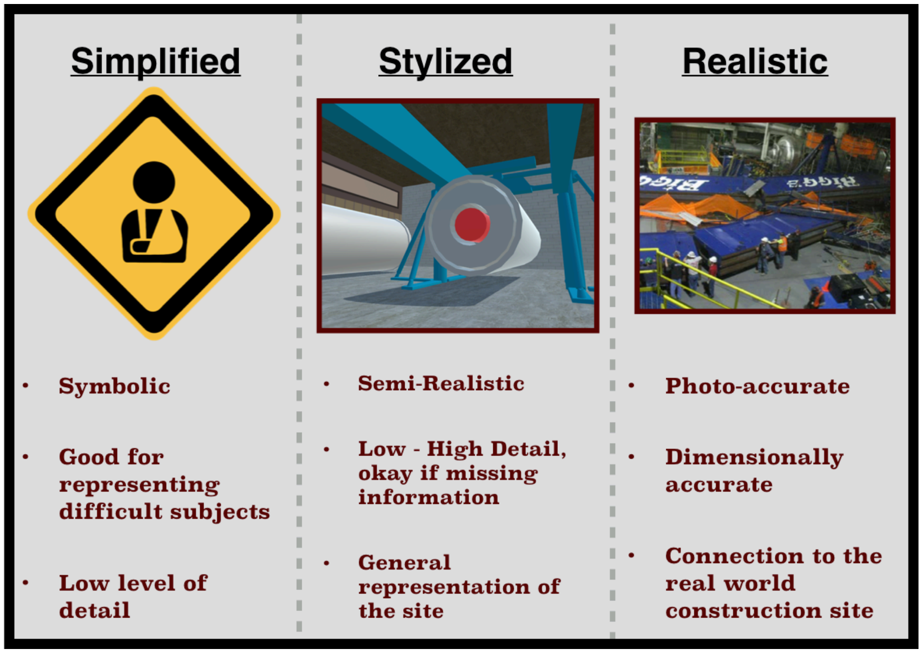

Figure 8.2: Visual Style

models and were more interested in the content associated with them. It is good to set the visual style early on, but it is okay to deviate from it when necessary. Styles can be mixed to create a cohesive scene. The purpose of choosing a visual aesthetic is create a baseline for design and modeling objects and features of the application.

8.5 Representing Temporal Changes

Many of construction incidents are the result of a series of errors over a period of time, which can range from a few days to a few weeks. This information is easier to show via graph or bullets points because time and the events that take place are constrained to two dimensions and discrete time steps. It is difficult to show this in a virtual environment when the user's sense of time is linked with the time they have spent interacting with the application. In this section we discuss four ways to represent a change in time. We implemented one and considered the others in our case study.

The top left panel is a graphic illustration of discrete time steps. Each discrete time step is either a group of incident events or a single event. Through an interface the participant can select a time step and the environment will change accordingly. The benefit of this is that the participant does not need to leave the environment to see a change in time and can fully explore a time period. This method was used in our application design.

The top right panel shows a slider method. The participant could scrub through the process of the wall being built at a pace the user dictated. Without a sufficient amount of details for the steps in between incident events, it is difficult to implement. This method is similar to commercial construction management applications that show the time line of a project by visually altering the model.

In the bottom left panel time progresses in a continuum in correlation with the participants location. For example if the participant moved alongside the wall the wall they would see it slowly begin to take shape and then collapse. The distance would equate to how much time has passed. This is useful for showing incidents in a linear matter, but not effect for areas that include multiple ground levels.

The bottom right panel is an exocentric view of the environment that is similiar to the world in miniature (WIM). The WIM was developed by Pausch et al. to navigate a virtual environment by using a handheld miniature model of the environment that they were in to change their location [28]. For this method we participant would be located in a simple environment with miniature models of the construction site representative of certain periods of time. The participant could either pick up the model to look at it as a whole or place themselves with it. This is particularly useful should their be multiple ground planes as seen in Case 02 (the partial crane collapse).

Regardless of how the change in time is shown, the participant should have a clear understanding of what time period they are learning about.

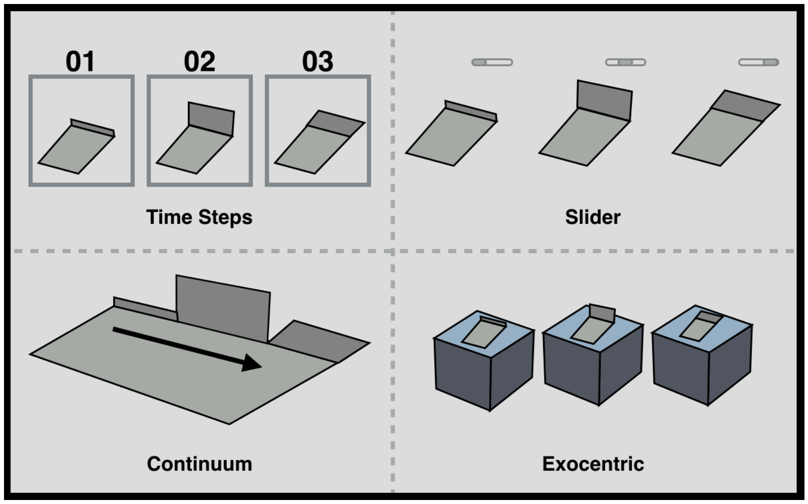

Figure 8.3: Temporal Representation Designs

8.6 Data Representation

In this section we discuss different ways to represent the information, providing insight on the applicability and our experience with it.

8.6.1 Textual

Using text is helpful to convey information that would be difficult to implement as a visualization or requires explanation. We will talk about text on a plane placed in 3D space, overlays and displays, and summarize our findings.

In our Case Study we implemented scalable and static planes, and used billboarding to represent the text in the 3D space. Scalable planes are planes that aim towards the users position and scale based on the distance from the user to the plane. They are useful for allowing the user to step back and look at the object as a whole, but are constrained in size by the other objects in the scene. They are not suitable for smaller items due to occlusion. Static planes should be used when there is either no room for the plane to rotate or it would ruin the aesthetic. The example in Figure 8.4 shows a situation where the speech bubble would not match up with the worker's head direction if rotated. Billboarding is a common technique for aiming a 3D plane at the user and useful for when the image does not need to be set in a certain orientation. For the desktop application, we primarily used billboarding for arrows. In the virtual reality version we used it for a majority of the information due because we could not use screen overlays.

Screen overlays is text, images, or interface that is overlayed onto the screen of the monitor. We suggest using this when applicable, because the location of the information is independent of the location of the user. Object overlays, like the scalable planes are mainly useful for larger items that can be seen at a distance. The heads up display is similar to a screen overlay, just in 3D space and tracking the movement of the head. The problem that frequently occurs is that the users are unable to read long pieces of text due to the slight movement of their head.

Out of all the types of textual representations we tried, only two are specific to the system device. The screen overlay only works on the desktop computer and the heads up display only with a VR system. For our purposes we found the aimed billboard to work best in VR and the screen overlay for the desktop computer.

8.6.2 Visual

Visual representation refers to information that does not require an explanation. For example, the participant knows the wall collapsed by looking at the environment with a virtual wall that has collapsed. How the information is presented is dependent on the visual aesthetic style, but can deviate to suit specific purposes. This type of representation is good for conveying the feeling of the environment, but not for remembering details about the incident. We noticed this in our user study when participants learned about the number of supports used to hold up the wall via text rather than looking around. When developing the application this should be taken into consideration.

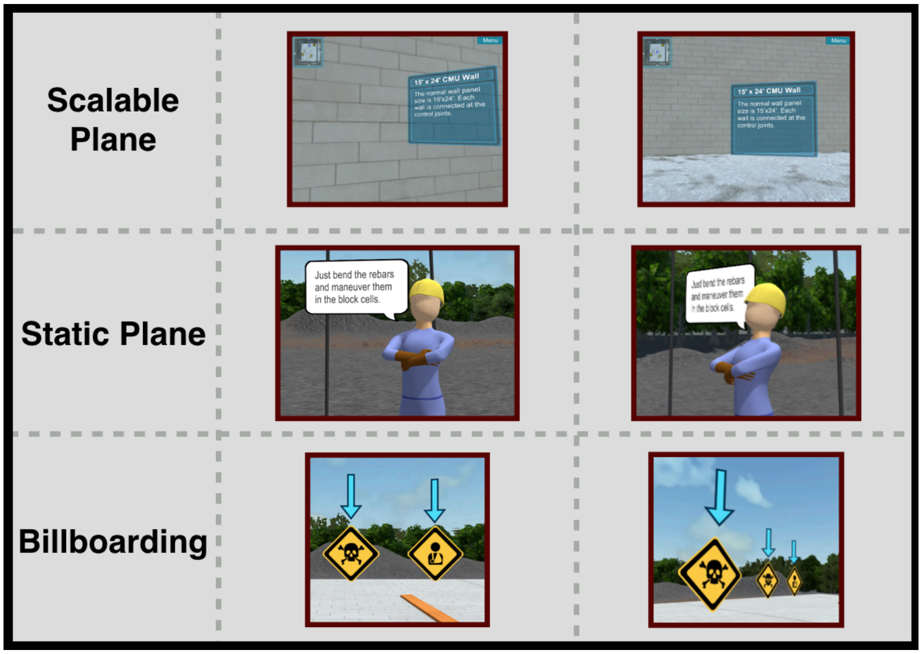

Figure 8.4: Text in a 3D Space

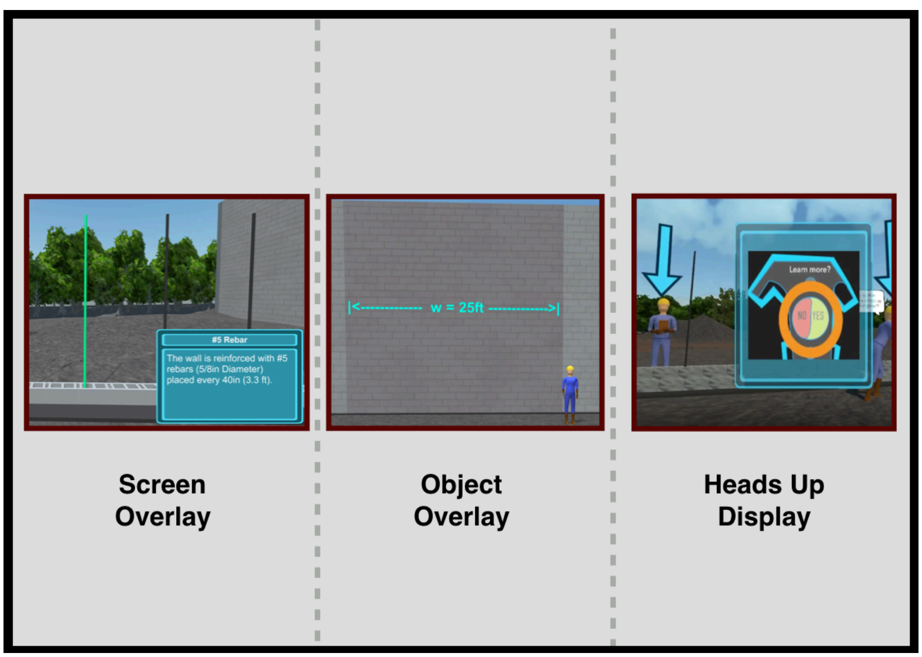

Figure 8.5: Text Overlays and Display

	VR	Desktop
Scalable Plane	✓	✓
Static Plane	✓	✓
Aimed Billboard	✓	✓
Object Overlay	✓	✓
Screen Overlay	-	✓
Heads Up Display	✓	-

Figure 8.6: Text Representation in VR and Desktop Computer

8.6.3 Spatial

The layout of the environments is challenging when given a limited amount of information. We suggest using images of the construction site to make simple models to fill up the environment space. If there is a large area, yet the accident occurs in a small portion, we suggest spreading information. We did this in our Case 01 application, where we spread out the documents and plans table and correct procedures and incident lessons (Figure 8.7).

8.6.4 Audio

Audio is a type of information representation that has room to be explored. Though we did not evaluate it in our studies, we considered how it would be used and the pros and cons (Figure 8.8). The benefit of audio that we were most interested in was the potential

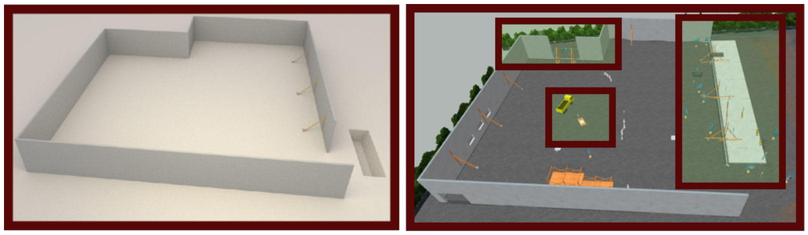

Figure 8.7: Environment Layout Based on Incident Report Drawings (Left), Environment Layout Based on Images and Textual Details (Right)

to reduce the amount of text. We realized that it was harder to read the information in virtual reality and considered having it read aloud. Similar to an object not fitting into the visual aesthetic style, the sound could not fit the environment and potentially distract the participant. Also, it was possible that the user would tune the information out because were busy looking around the environment.

Although adding audio adds an additional development task in finding or creating the audio, there are situations where audio is almost a necessity. For example, in Case 02 (The Partial Crane Collapse) the incident report states "...he heard a loud 'pop like a gunshot' immediately before the collapse. Another person...also reported to have heard similar pop sounds twice...". Because the noise was part of the environment details there was little justification in not including it.

8.7 Interaction Techniques within Virtual Environment

In this section we discuss different interaction techniques within the virtual environment. We will go over selecting objects, the user interface, and navigational control.

8.7.1 Selecting Objects

We acknowledge that applications may vary in function, but find it important to share our findings on selecting objects within the virtual environment because of the amount of feedback we received regarding controls. For the application we developed in the case

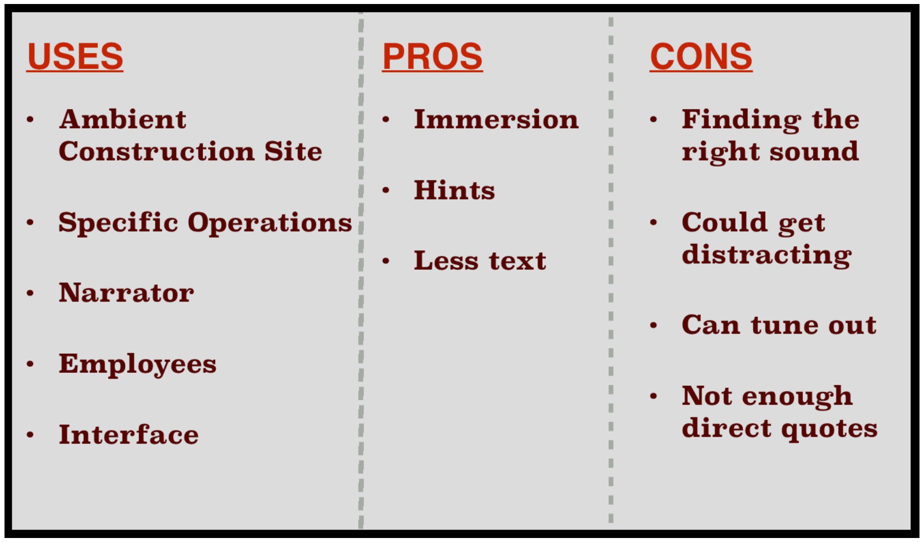

Figure 8.8: Audio Representation

study we created a system comprised of lessons, phases, and object selections. To complete a lesson the participant had to finish all the phases within the lesson by finding and selecting all objects within the phase. Selecting an object varied system device. If using a desktop computer then the participant had to click the object, read the information, and press "E". Similarly if the participant was using a Vive controller they would trigger click the object, read the information and then confirm that it was read by pressing a button. Many expressed that the confirmation was unnecessary and that they would rather be free to just click objects. Other were unsure of which objects could be selected and either left the area of clicked around until they found something. If allowing the user to select objects it should be clear what can be clicked and what is clicked. We showed this via a color change, but there are alternatives that can be implemented such as a color change that fades in and out.

8.7.2 User Interface

We mention the user interface because it played a big role in the applications we developed for both virtual reality and the desktop computer for knowledge acquisition. It is important to develop an interface that is easy and efficient otherwise it could hinder learning or not be used at all.

The interface that we developed in our case study and usability study was not evaluated until the informal user studies in the case study and usability study and the formal user studies in the experiment. For this reason a few of the features weren't intuitive resulting in little to no use. An example of this is the controls button on the menu. We created a few pages to help explain how to explore and interact with the environment. Out of all the participants, only one looked at them. By conducting a heuristic evaluation, such as Nielsen's Heuristics, beforehand we might have realized that we were relying on recall of the buttons rather than recognition [29]. Schneider's rules for interface design is also useful [30].

In our applications we included a map, menu, and text box. While there is no correct answer to what should included in the user interface, we suggest having a map to understand location and a way to get the information from the environment. Conducting a heuristic evaluation of the interface beforehand is useful for knowing how the participant will expect the interface to behave.

8.7.3 Navigational Control

Navigational control is how much control the user is given to explore the environment. We chose to conduct user studies with variations of the application based on three levels of navigational control to learn more about how it affects learning (Figure 8.9). In the Directed version participants were given a semi-automated tour of the environment, the Active version allowed for full navigational control, and Guided was a blend of the Di-

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

Figure 8.9: Properties of Navigational Control Levels

rected and Active versions. The quantitative data did not show a statistical difference in comprehension or knowledge learning based on the level of navigation. There was a statistical difference in time, suggesting that a directed level of control might be beneficial for an exploratory tool. While the quantitative data wasn't enough to form a conclusive answer on what level of navigational control should be used when exploring the environment, we did observe a trend in participant behaviour. The more freedom to explore the participant was given, the more likely they were to stray for the learning objective. However in the directed and guided variations the participants learning was more linear.

When deciding what level of navigational control to use, consider the learning objectives and the role of the participant.

8.8 Design Guidelines Summary

The guidelines were created from empirical evidence and quantitative results and are our suggestions for how to create an educational application. We acknowledge that the guidelines are subject to change should we design more virtual environments to contextualize construction incident reports.

9. SUMMARY AND CONCLUSIONS

Construction safety is important for preventing accidents and has the potential to be improved through interactive learning and construction incident reports. In this chapter we summarize our research and discuss our contributions and areas of further study.

9.1 Summary

In our research we conducted a case study in design where we developed two applications to contextualize construction incident reports. Each application was based on OSHA incident reports and included a virtual environment, desktop computer, and interaction techniques. The results of our case study was our observations on design choices, the applications, and feedback on usability and information representation. We also conducted a small usability study of an application in virtual reality with the virtual environment from one of the applications in the case study. We discussed the differences in interface design and results from a informal user study on the usability of the application. Through an experiment we collected quantitative data on how interaction techniques effect learning by creating two additional variations of one of the applications from the case study based on navigational control. Lastly we used the empirical evidence and quantitative data to create guidelines for developing an application to contextualize construction incident reports.

9.2 Contributions

Our main research contribution is the design guidelines we created to develop an application 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 the virtual environment. They are summarized in Figure 9.1. The guidelines

Data Preparation	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 that you choose will influence the interactions within the environment. Types of devices include a desktop computer and 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 an 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 and how depends on the amount of data and resources.
Interaction Techniques	To access the information the user must interact with then environment. This could include selecting objects, the user interface, and navigation.

Figure 9.1: Summary of Design Guidelines

serve as a foundation for contextualizing incident reports and can be expanded upon. Others may also use our research to help in the development of an application for the purposes of education.

We also provide quantitative and qualitative results from a user study showing how the level of navigational control affects learning and comprehension and influences behaviour. The results showed that there was no statistical difference in knowledge acquisition, comprehension, or spatial understanding for varying levels of navigational control. However, there was a significant statistical difference in time. This could suggest that a low level of control is suitable for knowledge acquisition and comprehension because the mean time spent using the application was the lowest. We believe more conclusive results can be gathered with inclusion of participant retention. The behaviour of the participants also suggests that levels of navigational control can influence the learning objective.

9.3 Further Study

Going forward in contextualizing construction incident reports we would like to examine more incident reports, investigate the important information, use building information modeling, and compare learning in virtual reality to the desktop computer. Creating more virtual environments to represent incident reports will help solidify our guidelines and should be pursued. Understanding what information is useful for safety education will help us define a learning objective beyond knowledge acquisition and comprehension. In this research we chose to contextualize as much information as possible, but we may find that it is not necessary. We want to look into using building information models instead of having to model the environment from the report details. It could greatly reduce visual development time but the increased level of detail may change how the information is received. We would also like to compare how participants learn using a desktop computer versus virtual reality. To do this we would like to create levels of navigational control for the VR version.

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APPENDIX A

FIRST APPENDIX

Text for the Appendix follows.

CASE 01 : Partial Masonry Wall Collapse			
	~=03/11/2013		footing poured
03/18/2013	03/26/2013		West Wall
03/27/2013	04/03/2013		East Wall
04/02/2013	04/05/2013		North Wall
04/04/2013	04/12/2013		South Wall
04/16/2013	04/22/2013		Loading dock wall
	04/18/2013	9:45 AM	East Wall collapse
	~=04/15/2013		two exterior braces removed
	03/19/2013		Beaver inspector reported correct reinforcing steel
	11/01/2012		HMHA architectural drawings
	08/14/2012		EMC structural drawings
Earliest	Factor 0	Accident	Contstruction Time
08/2012	03/2013	04/2013	1 month
CASE 02 : Temporary Overhead Crane Collapse			
	03/31/2013	7:45 AM	crane collapsed
	06/01/2012		Entergy and Siemens allience agreement
	09/12/2012		Siemens forwarded documents to Entergy
	07/01/2012		Siemens purchase order to Bigge Crane and Rigging, Inc
	03/30/2013		Final erection of temporary overhead crane began
	03/31/2013	3:00AM-4:00AM	First attempt to rig the stator
	03/30/2013	6:40 AM	the crane began to move the stator
	02/08/2013		Bigges sends lift plan to Siemens
Earliest			
06/2012	09/2012	03/2013	2 days

Figure A.1: Case Timelines

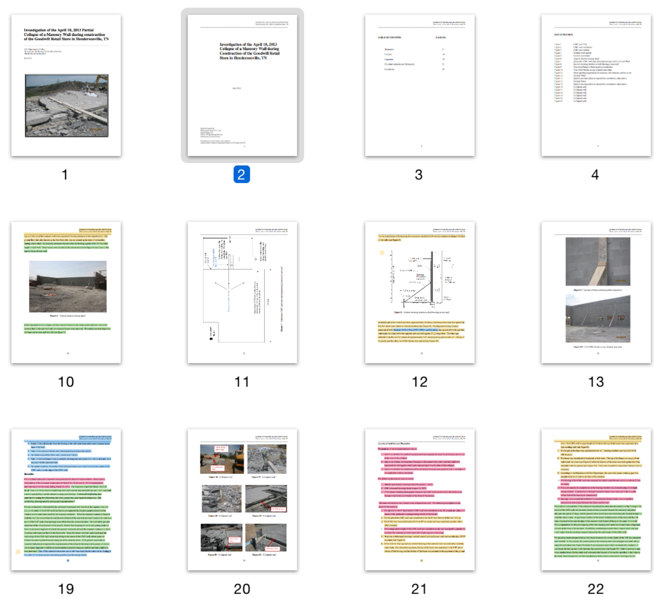

Figure A.2: Case 01: Incident Details, 01

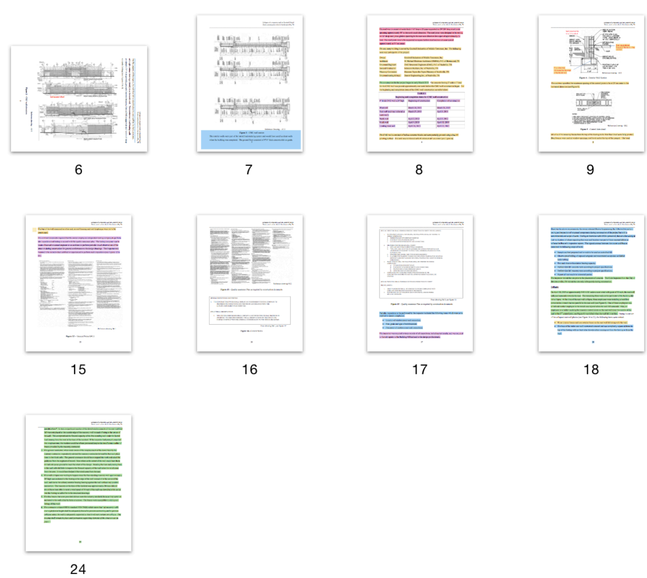

Figure A.3: Case 01: Incident Details, 02

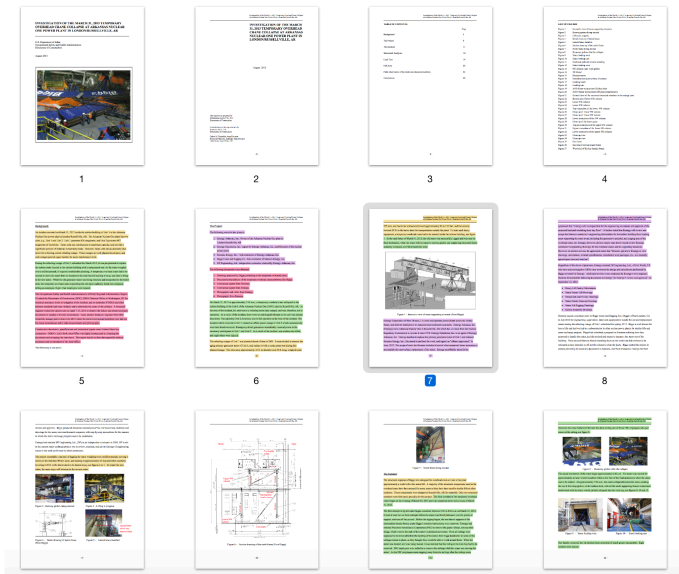

Figure A.4: Case 02: Incident Details, 02

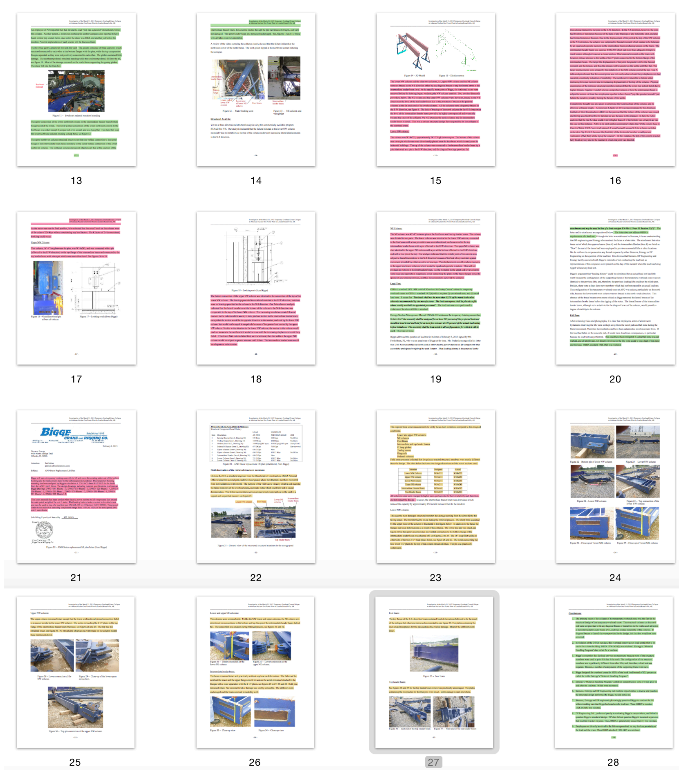

Figure A.5: Case 02: Incident Details, 02

APPENDIX B

EXPERIMENT DOCUMENTS

End Anim (Script)

Go to: 2e-05

module00_ŀ	module	20	0.5
hTo_wall_02	component	60	0.6
left	component	100	0.6
right	component	140	0.5
module01_ŀ	module	220	0.5
hTo_wall_02	component	260	0.46
top1_wall 1	component	300	0.46
cmuBrick2	component	340	0.46
hTo_wall_re	component	380	0.46
controlJoint	component	420	0.4
detailCanva:	plans	500	0.25
module03_t	module	580	0.46
polySurface	component	620	0.46
rangerShow	component	660	0.46
rangerBoss	component	700	0.46
bad_Rebar	component	740	0.46
rangerInspe	component	780	0.31
module04_t	module	860	0.46
brace_01	component	900	0.46
brace_06	component	940	0.46
brace_04	component	980	0.46
backflowPre	component	1020	0.46
BackflowRar	component	1060	0.46
rangerLadd	component	1100	0.92
t02_i02_ima	photo	1180	0.92
t02_i02_ima	photo	1260	0.92
t02_i01_ima	photo	1340	0.31
module05_t	module	1420	0.46
t03_i03_win	component	1460	0.46
t03_i04_inju	component	1500	0.46
ghost1	component	1540	0.46
ghost2	component	1580	0.92
t03_i06_ima	photo	1660	0.92
t03_i03_ima	photo	1740	0.92
t03_i04_ima	photo	1820	0.92
t03_i02_ima	photo	1900	0.92
t03_i05_ima	photo	1980	0.92
t03_i052-2_	photo	2060	0.92
t03_i01_ima	photo	2140	0.46

Figure B.1: Directed Navigational Control, Order of Learning Material

Please answer the following questions based on the information found within the virtual environment.

1 Please describe the basic details of the case (what was being built, what happened, etc.).

2. What was wrong with the rebars?

3. Who spotted the mistake?

4. What did the masonry contractor do?

5. What did the general contractor do?

6. What did the inspector report?

7. What was wrong with the braces?

8. Please describe each learning module.

9. How many workers were killed?

10. How many workers were injured?

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IRB APPROVAL DATE: 01/30/2017
IRB EXPIRATION DATE: 10/15/2021

Figure B.2: After Exploration Quiz

System Usability Scale

* Required

1. **Participant ID** *

   ....

2. **Version ID** *

   ....

3. **I think that I would like to use this system frequently** *
   Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

4. **I found the system unnecessarily complex** *
   Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

5. **I thought the system was easy to use** *
   Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

6. **I think that I would need the support of a technical person to be able to use this system** *
   Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

Figure B.3: Usability Scale

Experience Questionnaire

* Required

1. **Participant ID** *

....

Please rate the following on a scale from 1 (low) to 10 (high) or describe your experience.

2. **How interested would you be in using this to learn about construction safety?** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	High

3. **If you could use each system at home, how long do you think you would prefer to explore the environment?** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	High

4. **Do you have a good idea of the job site?** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	High

5. **How involved were you in the virtual environment experience?** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	High

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Figure B.4: Experience Questionnaire

Background Questionnaire

* Required

1. **Participant ID** *

Background Questionnaire

2. **Gender** *

Mark only one oval.

- Male
- Female

3. **Age** *

4. **Occupation** *

Mark only one oval.

- Student
- Other: .... *Skip to question 7.*

Student Information

5. **Major / Degree Specialization** *

6. **Degree Program** *

Mark only one oval.

- Graduate / Doctoral
- Undergraduate

User Usage

7. **Approximately how many hours a week do you use computers?** *

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Figure B.5: Background Questionnaire

	Score				
	1	**0.75**	**0.5**	**0.25**	**0**
Please describe the basic details of the case (what was being built, what happened, etc.)	Mentioned a wall falling	-	-	-	Everything else
What was wrong with the rebars?	Not centered, doesn't matter if they mentioned that it was bent.	Said misplaced, but did not use word "centered"	-	Didn't talk about position, but mentioned that it was bent later	Everything else
Who spotted the mistake?	The masonry contractor	-	a contractor	-	Everything else
What did the masonry contractor do?	Informed the general contractor about the mistake	-	-	-	Everything else
What did the general contractor do?	Told the workers to bend the rebars into place	-	Didn't stop work to properly fix it	-	Everything else
What did the inspector report?	Everything was good.	-	-	-	Everything else
What was wrong with the braces?	Bad design, removed early	-	Bad design || removed early	-	Everything else
Please describe each learning module.	-	-	-	-	-

Figure B.6: Short Answer Rubric, Comprehension