Development of an immersive game-based virtual reality training program to teach fire safety skills to children

Emily R. Ericson
Iowa State University

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Development of an immersive game-based virtual reality training program to teach fire safety skills to children

by

Emily R Ericson

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Human Computer Interaction

Program of Study Committee:
Shana Smith (Major Professor)
Steven Herrnstadt
Ann Thompson

Iowa State University
Ames, Iowa
2007

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ABSTRACT

Injuries from residential fires are often overlooked as a dangerous safety concern for children. While lectures and classroom learning techniques can be effective in mitigating this risk, studies have shown that kids retain information better if they are allowed to practice escape techniques. Virtual Reality (VR) has been used both to simulate situations that are too dangerous to practice in real life and as a tool to help children learn. This thesis presents the two stage development of the Fire Safety Project, a game-based VR training environment to increase children’s understanding of fire safety. In the first iteration students help firefighters to identify home fire hazards and then practice escaping from a simulated fire in a virtual environment. Surveys administered show that participants felt that they had learned something during training. Many young participants also wanted to have active control over the virtual environment. In response, the second iteration is more game-based and allows children to explore the environment independently and “zap” fire hazards with the help of a tracked 6DOF wand. A user study was carried out and results indicate that students enjoyed the program; however there were no concrete learning gains from the use of the VR simulation.
CHAPTER 1. OVERVIEW

The United States has one of the worst fire death rates of any developed country (Ahrens, 2004). On average in 2003 a person was killed by fire every 2 hours and someone was injured every 29 minutes (Karter, 2004). Children in the United States are especially vulnerable to fire danger. There are several factors that contribute to this risk, for example children hear at different frequencies than adults and are not as likely to be disturbed by standard fire alarms (Bruck, 2001). In addition, fire alarms can scare and confuse children; many will panic and try to hide when they hear a fire alarm (United States Fire Administration, 2002). This not only endangers their lives by prolonging their exposure to the fire event but also makes it difficult for rescuers to find them. One of the best methods for combating this problem is education. Programs that prepare children for fire emergencies have been developed as a means to combat this risk. These programs are usually presented during the school day; some examples of these programs are the NFPA Learn Not to Burn program and Risk Watch, both of which are designed to be integrated into standard school curricula (Kime, 2004).

To reduce fire injuries to children, most current fire prevention and safety instruction programs are delivered using lectures, videos, or pictures (Kime, 2004). While these programs are effective ways to expose children to fire safety ideas at an early age, studies have shown that the most effective means of teaching students to escape from a fire is to allow them to rehearse the actions necessary for escape (Holmes & Jones, 1996; Randall & Jones, 1993; Jones & Randall, 1994). Additional studies suggest that in general trainees learn better from hands-on exercises, rather than from traditional laboratory, classroom, or video training (Katz, Lesgold, Eggan, & Greenburg, 1996; Tam, Badra, Marceau, Marin, & Malowany, 1999; Wittenberg, 1995). It is impossible to use real fire environments for teaching children how to escape and protect themselves during fire emergencies due to
obvious safety issues. Thus, using traditional training methods, many children still might not be able to react properly when faced with a real fire emergency.

For critical situations like these, Virtual Reality (VR) has been successfully used to simulate real scenes in several dangerous task training programs. For example, Sandia National Laboratories used VR environments for training programs where classroom instruction was insufficient, but hands-on practice would have been dangerous, expensive, or logistically complex (Stansfield, Shawver, Rogers, & Hightower, 2005). One way to immerse learners in a scene for training purpose is the use of a Cave Automatic Virtual Environment or CAVE. A CAVE is a room that immerses users in a virtual environment by projecting stereoscopic images on four, five, or six walls. Multiple users can be in the CAVE at one time allowing for a shared virtual experience. Figure 1 shows a group experiencing a virtual tour in a four walled CAVE. This provides a fully immersive experience for users and suggests a good solution for training children to respond to fire emergencies.

It is important the children stay motivated in the virtual environment. Most participants will have had some kind of fire safety training in the past, and therefore we need to engage them in the material in a new way. Part of this will be accomplished by the newness of the technology that they will be experiencing. One highly motivating medium that most children will be familiar with is video games. By combining a game-like

Figure 1: CAVE with 4 walls.
application with sophisticated VR technology this research will create an immersive experience that users will find both motivating and exciting.

1.1 Fire Safety Training Programs

During the 1980’s fire education programs became popular in response to increasing levels of fire incidents in residential structures that are not subject to the same fire inspections as commercial buildings. One of the best ways to get information about fire safety into the home was to communicate important information through schools (Kime, 2004). The classroom activities package, *Learn Not to Burn*, was introduced in 1979 and is intended for use at 3 elementary school levels. There is also a pre-school and kindergarten program that was developed to address the safety risk to children younger than six. *Risk Watch* was introduced in 1998; it was designed to address other issues in addition to fire safety, such as seatbelt use among children. Figure 2 shows an elementary school class participating in a *Risk Watch* session. Such programs have effectively communicated basic fire safety principles to children, such as the “Stop, Drop and Roll” principle. Integrating these programs into certain grade levels helps to ensure that children get age appropriate

![Figure 2: A teacher leads discussion using RiskWatch (Kime, 2004).](image)
instruction and that they refresh their fire safety knowledge during the years when they are most vulnerable. Some research has gone into developing better ways to teach children the basic skills they need should they find themselves in a fire situation.

At Virginia Polytechnic Institute and State University researchers developed a program to teach children fire safety skills and at the same time mitigate the fear that the children felt about fire situations (Randall & Jones, 1993). Only children who reported that they felt “some” or “a lot” of fear about fire were included in the study. All the children in the study were first taught the appropriate procedures for escaping their bedroom during a fire situation, through verbal instruction, modeling, and practice. They were then divided into three groups, one group was given the reasons for each step, one was taught how to use self-instruction to moderate their fire related fear, and the third was asked to repeat the steps verbally in a group. There was no significant difference found in the fear levels among groups, however the first two groups showed significantly higher levels of learning than the group that merely repeated the steps. A second study by the same group concluded that providing children with additional information about fire safety and escaping from fire helps them retain the information better (Jones & Randall, 1994). A third study compared the learning effectiveness of rehearsal, an animated computer graphic, still pictures, and a control group. Results showed that both rehearsal and animated computer graphics showed significantly higher learning levels when compared to still graphics, and no training. Pagett, Strickland, and Coles (2006) developed a system for children who suffer from fetal alcohol syndrome (FAS). These students often have attention problems that lead to low retention rates and almost no generalization of skills. This makes them very difficult to teach and in the case of fire safety skills can put them at great risk for fire injury. After allowing the children to practice escaping from a fire in a video game, both with the help of an animated character and without, they found that most of the children were able to replicate the behavior several weeks later. The difficulty with traditional approaches to fire safety
education is that children often hear the same information repeatedly, so often in fact, that it becomes uninteresting and they stop paying attention. One way to add excitement to what is otherwise an old message is to use a new medium to communicate the information. One such medium that lends itself well to this training problem is VR.

1.2 Virtual Reality Background

Due to decreasing equipment costs and increasing processor speed, computer simulations have become more common over the last decade. As their complexity grows the applied uses of such technologies for education have become broader. A new area of computer simulations that is rapidly growing is VR. VR is generally defined as consisting of a multimodal, three dimensional, interactive, virtual environment. VR applications have been used by researchers to visualize data or natural phenomenon, and for entertainment purposes. For games, amusement park rides, and more recently exhibits in informal educational institutions like museums (Roussou, 2004; Lepouras & Vassilakis, 2005). Figure 3 shows an example of a VR exhibit at a museum in Greece. As interactivity in VR

![VR at Foundation for the Hellenic World](image)

Figure 3: VR exhibit at Foundation for the Hellenic World (Roussou, 2004).
applications has advanced it has become more feasible to apply the technology to sectors other than visualization and entertainment. Recently we have seen the development of many VR systems for training skills. It is widely accepted that people learn best by “doing”; VR affords learners the opportunity to complete an activity at very little cost, and no risk to themselves. In addition to these benefits some studies have shown that increased learner interest inspired by the use of new technology, may increase learning performance.

1.3 Games as Learning Tools

Since video games entered the market, almost thirty years ago, they have gone from a novelty item to a part of our everyday lives. Very young children learn through play (Verenikina, Harris, & Lysaght, 2003), and even at the college and corporate level instructors recognize the value of simulations and table top games in training specific skills (Cameron, 2002). Before they leave for college, today’s children will on average play 10,000 hours of video games (Mungai, Jones, & Wong, 2002). It is because of this popularity that researchers have begun to explore the potential applications of games for education. In addition to the research done using games to teach children with FAS how to protect themselves during a fire (Padgett, Strickland, & Coles, 2006), video games have also been used to teach children between the ages of 7 and 11 safe road crossing behavior (Thomson, Tolmie, Foot, Whelan, Sarvary, & Morrison, 2005). In this study children played a simple desktop game that asked them to help virtual characters decide when to cross the road. Children were guided by an adult facilitator, who framed the exercise and encouraged conversation between participants about good road crossing strategies. The authors argue that it is equally important to give children a conceptual understanding of how to complete the task safely as to allow them an opportunity to practice. The game in this study allows children to practice the conceptual skills necessary to safely cross roads with immediate feedback on how successful their attempt was, allowing them a chance to experiment with
different strategies in a way that is only available through this type of game. Researchers at Harvard are studying the impact of using multi-user virtual environments to help children think about science in a new way. The River City Project (Ketelhut, Dede, Clarke, & Nelson, 2006) allows children to interact in a virtual environment both with other students and with computer controlled agents that can be mentors or colleagues, and promotes deep thinking about science related topics. The promise of games for learning lies in the fact that they are fun, they provide immediate feedback, and allow users to experiment in a realistic environment with no real world consequences. From this background the goals of the fire safety project were defined. There are two iterations of the fire safety project; the first designed to operate as an immersive guided tour, and the second is an immersive VR game that requires interaction from users.

1.4 The Fire Safety Project

In its initial implementation the fire safety project was designed to be integrated into a fire safety program led by the Ames Fire Department. This project was an effort to make fire safety fun to learn about, and help children remember the steps they need to take should they ever find themselves in a fire emergency. Through collaboration with the fire department it was determined that the most important information for children to gain from our program was how quickly fire spreads and that crawling low can help you escape. This is both because it will allow you to see where you are going under the heavy smoke, and also because smoke is very hot. The most important goal of the program was to get children thinking about fire emergencies before they actually find themselves a part of one.

The traditional home fire safety training session focuses on what to do if you wake up to the smoke alarm. The appropriate steps in this example include, rolling out of bed, crawling to the door, checking to see if the door is hot, and finally opening the door to look
Performing these steps in a CAVE environment would be difficult if not impossible. Crawling is an activity that translates from the real world well, but rolling out of bed is not possible with a virtual bed, and feeling a virtual door to see if it is hot is also a confusing idea. The simulated fire event was moved out of the bedroom and set during the day, this allows the children practice in escaping without the complications of the bedroom scenario. It was also necessary to ensure that users were comfortable with the experience and that it would not be stressful for them. One of the major concerns early in development was that young users might be scared in a simulated fire event. To address this issue, children always experience the fire event in groups.

The first implementation of the fire safety system asked children to look for fire hazards as they moved through a virtual environment with the help of a firefighter. They then practiced escaping from a simulated kitchen. The virtual environment consists of a large house that is full of fire hazards, such as overloaded outlets and unattended candles. Figure 4 shows children pointing to the fire hazards they see in the virtual environment. Navigation is controlled by a researcher and children are passive observers of the technology. Many children complained that they wanted to be able to explore the house independently; the new game-based version of the fire safety program addresses this issue and in addition makes several improvements to the interface, including ambient sounds and a novel interaction.
technique to further engage users. Children are encouraged as in the previous study to identify as many home fire hazards as they can in the virtual environment and then practice escaping from a simulated fire event. In this implementation children are free to explore the environment on their own and have new way of interacting with the environment by removing dangerous hazards instead of just talking about them. Through this simulation children are able to gain firsthand experience in how quickly a fire can grow and spread and what to do should they find themselves faced with a real-life fire emergency. This thesis describes the development of both parts of the Fire Safety system and includes user testing to judge the effectiveness of the implementation.

1.5 Thesis Organization
This thesis includes two papers written during the development and testing of the fire safety program. The first paper, submitted to Fire Technology, describes completion of the initial system and a pilot study that was carried out. The second paper, prepared for Virtual Reality, describes the newest game-based version of the application which includes the addition of new navigation and rendering systems.
CHAPTER 2: USING IMMERSIVE VIRTUAL ENVIRONMENTS FOR REALISTIC LIFE-SIZE FIRE PREVENTION AND SAFETY TRAINING FOR CHILDREN

A paper submitted to *Fire Technology.*

Emily Ericson¹ and Shana Smith²
Human-Computer Interaction Graduate Program
Virtual Reality Applications Center
Iowa State University

Abstract

Injuries from residential fires are often overlooked as a dangerous safety concern for children. While lectures and classroom learning techniques can be effective in mitigating this risk, studies have shown that kids retain information better if they are allowed to practice escape techniques. Virtual Reality has been used to simulate situations that are too dangerous to practice in real life. This paper presents a fire safety program that combines classroom activities and small group interaction with fire professionals with a virtual simulation of an at-risk house. Students help firefighters to identify home fire hazards and then practice escaping from a simulated fire in a virtual environment. A CAVE is used to immerse participants in the fire scene.

¹ Graduate student in Human Computer Interaction, Iowa State University and primary researcher and author

² Associate Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, author for correspondence
1. Introduction

The United States has one of the worst fire death rates of any developed country (Ahrens, 2004). On average in 2003 a person was killed by fire every 2 hours and someone was injured every 29 minutes (Karter, 2004). Especially vulnerable are the youngest of our society who can be confused by fire alarms and are at twice the risk of fire death than the general population (Ahrens, 2004). To mitigate this risk many programs have been developed to increase awareness of fire dangers among young children. For the most part these programs involve the use of instructional videos and lectures to raise awareness and prepare children should they become involved in a fire.

Examples of these programs are the NFPA Learn Not to Burn program and Risk Watch, both of which are designed to be integrated into standard school curricula (Kime, 2004). Studies have shown that the most effective means of teaching students to escape from a fire is to allow them to rehearse the actions necessary for escape (Holmes & Jones, 1996; Jones & Randall, 1994). However, it is impossible to use real fire environments for teaching children how to escape and protect themselves during fire emergencies. To reduce fire injuries to children, most current fire prevention and safety instruction programs are delivered using lectures, videos, or pictures (Kime, 2004). Studies suggest that trainees learn better from hands-on exercises, rather than from traditional laboratory, classroom, or video training (Katz, Lesgold, et al., 1996; Tam, et al., 1999; Wittenberg, 1995). Thus, using traditional training methods, many children still might not be able to react properly when faced with a real fire emergency.

For safety reasons and to remedy the shortcomings of traditional training methods, recently virtual reality (VR) has been successfully used to simulate real scenes in several
dangerous task training programs. For example, Sandia National Laboratories used VR environments for training programs where classroom instruction was insufficient, but hands-on practice would have been dangerous, expensive, or logistically complex (Stansfield, Shawver, Rogers & Hightower, 1995). Programs also seem to carry more weight with students if they are delivered by an authority figure in the community, often a firefighter or a policeman (Warda, Tenenbein & Moffatt, 1999).

One way to immerse learners in a scene for training purpose is the use of a Cave Automatic Virtual Environment or CAVE. A CAVE is a room that immerses users in a virtual environment by projecting stereoscopic images on four, five, or six walls. Multiple users can be in the CAVE at one time allowing for a shared virtual experience. At Iowa State University, the C6 is a 10ft x 10ft x10ft room where all 6 sides are projection screens. This provides a fully immersive experience for users.

This paper presents the design and implementation of a fire safety training program for K-12 children, using immersive CAVE-based VR. Children were brought into safe but realistic life-size fire environments to experience being in a fire environment and receive “hands-on” fire training. Firefighters from the local fire department participated in program delivery. By combining many proven techniques in fire safety training with a VR experience it is possible to engage children in learning about fire safety in a new way.

The rest of this paper is organized as follows: first we present related work in training using VR and novel approaches to teaching fire safety. Then we describe the design of our VR system. This is followed by a discussion of the integration of the VR component into a complete training program. We then discuss our pilot study and evaluation methods. Finally we present a discussion of our results.
2. VR in Skill Training

While many efforts have been made to expose children to fire safety for the first time at an early age, and to continue to do so through classroom activities as they grow, retention of information to the point of behavior modification and generalization to other scenarios is most likely for children who have actively practiced safety skills including crawling low under smoke and practicing an escape plan (Warda, Tenenbein & Moffatt, 1999). Training programs have been developed to address groups other than school aged children. At college campuses some interest has been taken recently in raising fire safety awareness due to the growing number of fire injuries and deaths on college campuses. Some of these activities include a simulated smoke filled hallway that students must crawl through and a mock dorm room that is set on fire to demonstrate the intense heat and quick spread of fire (Comeau, n.d).

VR has also been applied to firefighter training systems. The Navy has experimented with using VR to train firefighters. Traditionally Naval firefighters trained on a retired battleship. Instructors create various kinds of fires, and the trainees are asked to respond to the situation. VR has been used to create a virtual model of a training ship; researchers then created several sample missions and asked trainees to perform them both on the actual ship and in the virtual environment. Trainees wore an HMD and used a joystick to navigate through the virtual ship. Researchers found that the trainees demonstrated similar levels of learning whether they were trained in the actual ship or in the virtual environment with significantly less risk involved than traditional training methods (Tate, Silbert & King, 1997). A slightly different system has been developed to help train firefighters to assume command positions during a fire situation (St. Julien & Shaw, 2003). This system allows the trainee to
take control of several virtual firefighters at a fire scene. The trainee issues orders that are carried out in the virtual scene, the program then simulates the fire’s response to the actions. It not only simulates smoke and fire flow but can also simulate structural integrity adding a level of complexity that is present in real world emergencies but not often in real-world training exercises due to safety concerns.

VR has been recognized as a way to immerse participants in situations that might otherwise be too dangerous to experience. At the University of Queensland in Australia, researchers have developed a series of VR training tools for miners. Mining is a very complex and dangerous occupation, and VR helps to train miners in accident prevention (Kizil & Joy 2001). VR is also used to train miners for dangerous tasks such as driving a truck into the mining pit. A similar system was developed to train refinery workers in Austria (Haller, Kurka, Volkert & Wagner, 1999). The user wears a head mounted display (HMD) and uses a wand for navigation and interaction. The instructor can initiate any of a series of emergencies from a separate application on a desktop computer. The student is then graded, losing points whenever s/he initiates an incorrect action that would lead to injuries in a real world situation. This helps refinery workers to prepare for real life incidents.

A virtual training application has also been developed to handle high risk, low frequency events such as terrorist attacks (Henderson, 2005). This system immerses a learner in a virtual academy through a desktop system, s/he then goes through basic training, then participates in a simulated event, which is then followed by a debriefing. Another example of a system designed to prepare first responders for the possibility of terrorism is the BioSimMER (Stansfield, Shawver, Sobel, Prasad & Tapia, 2000). This application allows trainees to enter a virtual emergency scene using HMDs and trackers on their arms and back.
This system makes excellent use of VR to provide an experience that would otherwise be too expensive or too dangerous to create realistically. However, this system is not a model of the actual emergency only the aftermath, making environmental effects less important in this system.

Another system that attempts to prepare users for emergency situations has been developed that focuses on allowing the user to live through a stressful and sometime dangerous scenarios (Ponder et. al., 2003). In this study the user faces a large projection screen that helps provide a sense of immersion. They navigate through natural gestures and interact with the environment through natural speech. A researcher interprets the user’s movements and commands and passes them to the system. A “Virtual Assistant” then carries out any commands issued by the trainee.

3. System Design

In this study a life-size fire prevention and safety training system was developed in a CAVE-based VR environment. The VR environment allows the immersion of young children in a realistic fire situation as a part of a fire safety training program. This allows the student not only to rehearse evacuation skills but also to do so in a realistic fire environment. In addition, firefighters were invited to be active participants in the training program, giving the children a recognizable authority figure to learn from.

Working with the Ames Fire Department, a list of objectives was developed for the VR fire safety training application. The first goal was to allow the children to participate in some sort of “escape” from a fire situation. This should include the need for children to crawl low so as to be able to see in spite of the smoke above them. This
necessitated a realistic smoke simulation that would be thick enough to obstruct the view of anyone standing in it, but controlled enough that it stayed a certain distance above the floor. Figure 1 shows the final controlled smoke from a view close to the floor. The second goal of this application was to communicate to the participants in the program that fire hazards are very common and are often overlooked. People often do not recognize potentially dangerous situations such as the fact that having toys on the stairs can be considered a fire hazard. Figure 2 shows examples of this and other fire hazards.

An extensive list of common home fire hazards was developed in conjunction with the fire department. From that list, food left on the stove was chosen as the one that would ultimately cause the fire event in our simulated home. This was done for a variety of reasons, the most influential being that cooking fires are the leading cause of residential fire events. Figure 3 shows some of the most common fire hazards in our program.
Figure 1: Controlled smoke allows for visibility near the floor.

Figure 2: Three common home fire hazards.
This system was designed using VRJuggler, an open source VR library (http://www.vrjuggler.org/), and SGI's Performer scene graph (http://www.sgi.com/products/software/performer/).

The next challenge was to simulate a fire situation so that the firefighters could effectively demonstrate proper escape techniques. Several options were considered for simulating smoke in the model including environmental fog and volumetric fog. After testing these it was determined that the most realistic smoke simulation was provided by

Figure 3: Common Fire Hazards

(a) Cigarettes on sofa
(b) Books in front of fire.
(c) Unattended candles.
(d) Overloaded outlet.
Performer’s pfuSmoke utility library. This utility was used to create clouds of smoke that would envelop the upper portion of the room that contained the fire.
This simulation was designed to run in a CAVE with six walls. This provides the greatest sense of immersion for participants. With the help of an architecture student, a house model was developed and populated with the hazards that had been discussed with the firefighters. It is important that participants can see the smoke move over their heads as they crawl from the simulated house. The finished model of the home is shown in Figure 4. The house is very large compared to what most of our participants would be used to; however, this somewhat exaggerated size improves navigation through the house in the CAVE.

4. Study Description

We invited several groups of girl scouts and boy scouts and their parents to participate in our fire safety program. We divided each group into two smaller groups. There were approximately seven students in each group. One group participated in classroom activities while the other went through the virtual fire safety training; the groups would then switch activities.

The classroom activities are dependant on the age of the group of students. Figure 5 shows a firefighter leading a classroom discussion for a group of boy scouts. For participants older than 12 the activities consist of a presentation given by a firefighter explaining fire hazards and important escape techniques, then the students watched a video demonstrating how quickly a real fire can spread through a house. Younger participants are given a shortened version of the lecture and then shown a longer; cartoon video that explains how fires burn and what they can do to escape. This video is geared toward the younger audience.
The VR simulation consists of two parts. In the first part the participants move through the virtual home and point out possible fire hazards with the help of a firefighter. In figure 6, a group of girl scouts identify hazards with the help of a firefighter.

Then participants move to the kitchen where they discover one of the most dangerous hazards in the house: food left on the stove. The food is already producing some smoke when participants enter the kitchen. When the fire is triggered the smoke begins to grow and spread through the room very quickly, as shown in figure 7. The firefighter then triggers a real fire alarm. As the simulated smoke fills the room, the firefighters demonstrated that crawling low in a room full of smoke improves visibility. Figure 8 shows a fireman helping participants to identify an exit in a room darkened by smoke. They were able to show how recognizing floor coverings can help you navigate through a house and landmarks like power
Figure 7: Fire caused by food left on the stove.

Figure 8: A firefighter helps participants identify an exit as the room fills with smoke.
outlets (as shown in figure 1) can aid you in finding an escape route through heavy smoke. The students then quickly “escape” from the fire and move to a meeting place in the yard of the house.

5. Evaluation Method

An informal survey was developed and administered after both groups had completed both the virtual training and the classroom lecture. The survey consists of ten questions: the first two questions are demographic. Figure 9 shows the demographic breakdown of our participants.

The third question dealt with how much the students felt they had learned during the training session. Figure 10 shows responses to this question. Most students felt the level of knowledge they had learned is high or very high. The fourth question asked whether participants were afraid at any time during the training. One of the major concerns of this project prior to implementation was to make sure that our simulation was as realistic as possible but without scaring any of the children who participated. Figure 11 shows responses from all of the people who participated in our simulation indicating how scared they felt during the simulation. The survey results seem to indicate that most of the participants definitely were not scared by the simulation with almost all of the participants indicating 1 for their level of fear during the experience. However, two of the younger participants in the program were too scared to enter the CAVE at first. One of them did participate later and enjoyed the experience very much.

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Figure 9: Study Demographics
Figure 10: How much have you learned about fire safety during this training program?

Figure 11: Did you ever feel frightened while in the fire scenes in the CAVE?
Figure 12: Choose the words that describe how you felt during the training in the CAVE.

Figure 13: Choose the types of fire safety training you have had.
The fifth question in our survey asks the participants to describe how they felt during the simulation by choosing one or more descriptive adjectives. Figure 12 shows the range of responses for each descriptor. The descriptors were kept as simple as possible because some of our participants were as young as eight. Most of the descriptors chosen were positive; students were engaged by our system, in fact the top four descriptors chosen were “Interested”, “Awesome”, “Fun”, and “Excited”. They were excited to use a technology that was new to them and found the whole experience enjoyable. We then asked participants to tell us about their previous fire safety training experiences. Figure 13 shows the responses to this question. Almost all the participants had participated in some form of fire safety training, and a video or television show was the most popular form of training.

The next question asked which form of training they enjoyed the most; 75 of the 85 people surveyed listed virtual training as their favorite forms of training. The enthusiasm
shown by the children who participated was especially encouraging, as they are the group most in need of fire safety knowledge. Figure 14 shows the results of this question.

The final three questions in our study were open-ended questions. We first asked participants to tell us the most important thing they learned during the program. In response to this question participants mentioned specific fire hazards they had seen, how fast fires can spread, and specific instructions the firefighters had provided such as how often to change the smoke detector and the procedure in a fire emergency. We then asked what they liked best about the simulation. Responses to this question focused on the technology being used in the simulation. Participants mentioned the graphics, navigation, and dynamic smoke as their favorite things. Finally we asked what they liked least about the experience; many participants did not provide an answer to this question or wrote “nothing”. Those who did provide an answer mostly wanted more freedom to move about the house or mentioned that the refresh rate of our application was not high enough and that they felt dizzy. These responses are more thoroughly discussed in the next section.

6. Discussion

The use of VR made a large impact on the young participants in the program. Most were very excited when they first arrived; certainly more so than they generally are before a fire safety lecture. While almost all of the participants had received some form of fire safety training, most had never experienced VR before and were therefore able to look at material that they had perhaps seen before in a different way. Part of the problem with lectures and classroom training exercises is that children get bored and stop paying attention. This VR-based fire safety training program allows students to not only experience a new type
of technology through a hands-on exercise, but also to have small group interaction with firefighters. This often leads to them asking questions they had not thought of before. For example during our training sessions students asked about what pets do during fire emergencies and why the fire trucks in this community are white instead of the traditional red. Often parents who participate learn something too. Many of our parents expressed surprise when they learned how often smoke detectors should be replaced.

Most participants indicated that they enjoyed their VR experience; however, there were a few complaints that seemed to come up often. The first of these is the speed of our simulation. The model we used is very detailed and producing realistic smoke is a memory intensive operation so at times the program can be slow or jerky in the VR environment. This upset the illusion of immersion for some of the participants and may in some cases have added to any discomfort felt by the participants. In the last part of our survey participants were asked what they liked least about the experience, 15% mentioned the slow speed as a problem, 16% mentioned that they felt dizzy or uncomfortable during the session; this may be related to the slow speed of the application. Another common complaint was the lack of ambient noise in the simulation. With the exception of the sound of the fire alarm, sounds had not been considered for the simulation. However, some participants mentioned that it would be a more realistic experience with ambient sound. Despite these issues most participants listed VR training as their favorite method of fire safety training, 88% selected it as at least one of their favorite forms of training.

Measuring learning is one of the greatest challenges of a training program. In the survey the children and adults who participated were asked to rate how much they learned during the experience. More than 70% reported learning 4 or 5 on a five point scale. While
this is not a concrete measure of skills acquired, it suggests that participants at least felt that they had gained a great deal of information during our program. In addition the concepts covered during the program seemed to stick with our participants. After they completed the training we asked them to tell us about the hazards they had discovered in the house. All of the children were able to provide examples of the hazards they had found and even thought of a few that had not been modeled in our simulation. This result reinforces Sulbaran’s and Baker’s findings that learners usually enjoyed the VR training more and were able to retain the knowledge longer (2000).

7. Conclusion

VR has the potential to become an invaluable method of training in situations where actual hands-on training is too dangerous. VR seems to be an especially useful tool when dealing with children as they are excited to use the technology involved. In this paper we have described a program to enhance the understanding of fire safety techniques by young children using an immersive CAVE-based VR. The program successfully engaged the young participants and helped them gain demonstrable knowledge about fire hazards.

In the future we plan to add a school fire location to the current house simulation. This will allow participants to practice escaping from a fire in a school setting. We also hope to find a way to improve the efficiency of our program to increase speed and hopefully make participants feel more comfortable in the environment and decrease the discomfort experienced by users.
CHAPTER 3. USING IMMERSIVE GAME-BASED VIRTUAL REALITY TO TEACH FIRE SAFETY SKILLS TO CHILDREN

Prepared for submission to Virtual Reality

Emily Ericson
Iowa State University
ejericson@iastate.edu

Shana Smith
Iowa State University
sssmith@iastate.edu

Abstract

Virtual Reality has been used both to simulate situations that are too dangerous to practice in real life and as a tool to help children learn. This paper presents an immersive virtual reality application designed to help children learn about fire hazards and practice escape techniques. Through a game-like interface and innovative interaction techniques, students are motivated to explore the virtual world. A CAVE is used to immerse participants in the fire scene. Rather than being a passive viewer, users are given full control to navigate through the virtual environment and to interact with the virtual objects using a game pad and a 6DOF wand. Students identify home fire hazards with a partner and then practice escaping from a simulated fire in a virtual environment. A user study is carried out and results indicate that while there was no significant change in learning outcomes due to the use of the

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3 Graduate student in Human Computer Interaction, Iowa State University and primary researcher and author

4 Associate Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, author for correspondence
immersive environment, students are engaged by the technology and find the experience fun and engaging.

1 Introduction

Due to decreasing computer equipment costs and increasing processor speed, computer simulations have become more common over the last decade. As their complexity grows, the applied uses of such technologies for education become broader. A new area of computer simulations that is rapidly growing is virtual reality (VR). Because VR allows for full submersion into a virtual environment, it has many applications to training as dangerous situations can be modeled with no risk to the user and many of the same benefits of learning-by-doing are still noted (Stansfield, Shawver, Rogers, & Hightower, 2005).

VR systems can be used in situations where it would be too dangerous or logistically impossible to have users participate in an actual event. For example, researchers have developed a series of VR training tools for miners. Because of the danger mining presents, it is important that miners are well trained. Using VR has helped prepare miners for dangerous situations that cannot be addressed through traditional training methods (Kizil & Joy, 2001). A similar system was developed to train refinery workers (Haller, Kurka, Volkert, & Wagner, 1999). The user wears a head mounted display (HMD) and uses a 6DOF wand for navigation and interaction. An instructor can initiate any of a series of emergencies from a separate application on a desktop computer. The student is then graded, losing points whenever s/he initiates an incorrect action that would lead to injuries in a real world situation.
VR has also been applied to firefighter training systems. Traditionally Naval firefighters train on a retired battleship. Instructors create various kinds of fires, and the trainees are asked to respond to the situation. Using VR, trainees can perform missions in a virtual environment. Researchers found that the trainees demonstrated similar levels of learning, independent of whether they were trained in the actual ship or in the virtual environment, with significantly less risk involved when using the virtual environment (Tate, Silbert, & King, 1997). Another application that deals with fire in VR is the VRFire system developed by Sherman et al. (2007). This system allows a user to visualize the growth and spread of a wildfire in an immersive VR environment. The user may navigate the scene and set the parameters before the start of the fire. VR has also been used to train both emergency first responders and their commanders. As many as six first responders can participate in a scenario while wearing HMD’s. They make decisions based on directions by a commander who uses a large screen stereo display to view the whole scenario area (Li, Zhang, Xu, & Liu, 2005).

Several VR systems have been developed specifically for children. Some focus on communicating a key concept, while others are general “sandboxes” that allow children to explore the environment. One example of the former was developed to teach children that the earth is round. This concept can be hard for children to grasp because all of their day-to-day experience with the earth conflicts with this fact (Ohlsson, Moher, & Johnson, 2000). Children worked in teams of two to collect objects on a virtual asteroid. One child acted as the astronaut on the face of the asteroid in a CAVE, the other acted as mission control, helping their teammate navigate from an ImmersaDesk™. The children were able to translate their experiences with the asteroid to the way they think about the earth. Another difficult
concept for children to understand is comparing fractions. Fractions with bigger numbers in the denominator are actually smaller than those with smaller denominators which seems counterintuitive to young children. Roussou and Slater (2005) developed a virtual playground application to help children grasp this concept. Children were asked to help several animated characters place playground equipment based on what fraction of the area of the whole playground they occupy. While there was no evidence that any concrete learning took place, students were given a new context in which to think about fractions (Roussou, Oliver, & Slater, 2006). A VR learning application was designed for older students to help them grasp difficult concepts in geometry (Kaufmann, Schmalstieg, & Wagner, 2000). In this study, students wore a HMD to view the virtual world. They used a pen interface and buttons were drawn on an actual notebook that the user held in his/her hands. All of the users in the pilot study expressed positive feelings about the VR interface and their confidence with geometrical concepts.

One system of the latter variety is the NICE project (Roussou, Johnson, Moher, Leigh, Vasilakis, & Barnes, 1999). This system allows children to interact with a virtual garden. Children can plant seeds, provide sunshine and water for their plants and watch them grow. This system lets children experiment with different kinds of plants and giving the plants varying levels of water and sunshine. Researchers found that this open ended style of play engaged children and encouraged them to create narratives to go along with their experience.

Games have also been shown to be an effective means of engaging children in material that it would otherwise be difficult or boring for them to learn. For example a game was designed to teach children with FAS how to protect themselves in the event of a fire, and
another has been designed to help children learn to cross the street more safely (Padgett, Strickland, & Coles, 2006; Thomson, Tolmie, Foot, Whelan, Sarvary, & Morrison, 2005).

This paper presents the design of an innovative system to teach upper elementary school children about fire safety, using game-based immersive VR. First, a pilot study for the previous version of this system and the issues are addressed. Then, the design of the new game-based system is introduced. This is followed by a discussion of the technical issues encountered in the design of the new system and design and results of a user study. Finally, a description of future work is given.

2 Pilot Study

The Fire Safety project is an effort to make fire safety fun to learn about, and help children remember the steps they need to take should they ever find themselves in a fire emergency. Through collaboration with the fire department it was decided that the most important information for children to gain from our program was how quickly fire spreads and that crawling low can help you escape. This is both because it will allow you to see where you are going under the heavy smoke, and also because smoke is very hot. The most important goal of the program is to get children thinking about fire emergencies before they actually find themselves a part of one.

The first iteration of this system asked children to look for fire hazards as they moved through a virtual environment with the help of a firefighter and a graduate student navigator. They then practiced escaping from a simulated kitchen fire. The virtual environment consisted of a large house that was filled with fire hazards, such as overloaded outlets and unattended candles. In the pilot study, children had a firefighter in the virtual environment
with them to provide motivation and help them stay on task. The children are passive observers of the technology. Many of the children complained that they wanted to be able to actively explore the house. While they enjoyed the new technology they were frustrated that they could not interact with it directly. With the prevalence of video games with today’s youth, (Mungai, Jones, & Wong, 2002) they expect to be able to interact with technology, simply viewing the virtual environment is not enough to keep them engaged (Roussou, 2004). This issue was addressed in the next version of the program. In addition, several improvements were made to the interface, including ambient sounds and a novel interaction technique that engages users in a more active way.

3 New Game-Based System Design

There were several special concerns in the development of a system such as this one that aims to both entertain users and provide users with information about as important a topic as fire safety. Without trivializing the message, it is important that the application still remain fun and accessible to young children.

3.1 Basic System Components

There are three primary open source software libraries that are integrated into the Fire Safety application. Using these libraries allows this research to focus on the educational message and interaction as opposed to low level features of the application.

3.1.1 VRJuggler

The VR component of the application is built using VRJuggler (http://www.vrjuggler.org/). This open source cross-platform VR library allows for portability between VR systems, from desktop based to fully immersive CAVE systems simply by changing a configuration file. VRJuggler contains several separate components
within it so that a developer may choose only those components which are necessary for their application and ignore anything they do not need. Some examples include Sonix, a simple sound library, Gadgeteer, an input device manager, and support for clustered applications. By defining an ApplicationData variable, a developer can specify what information needs to be shared across a cluster and the application framework will make sure the data is updated each frame.

3.1.2 OpenSceneGraph

The graphics in the Fire Safety application utilize OpenSceneGraph (OSG; http://www.openscenegraph.com/index.php). This open source 3D graphics library that implements a full featured scene graph containing support for graphical switches, level of detail and support for loading many different types of files. It is written in C++ using OpenGL and has been used for a variety of applications including flight simulators, games, VR and scientific visualizations.

3.1.3 Open Physics Abstraction Layer (OPAL)

OPAL (http://ox.slug.louisville.edu/~o0lozi01/opal_wiki/index.php/Main_Page) is an open source physics engine that provides a wrapper around lower level physics interfaces. The two main goals of this project are “to provide a high level physics interface” and “to provide an abstract interface that is independent of the underlying physics engine.” The project has focused mostly on the first objective; the ultimate goal being to abstract the underlying physics engine to the point where engines can be swapped without any changes being made to an applications code. Currently OPAL only supports Open Dynamics Engine (ODE) on the back end. The Fire Safety game uses OPAL as a high level interface for ODE.
3.1.4 Realistic Smoke

One of the biggest challenges in the implementation of the fire safety project was a requirement defined not by the intended users, but by the Ames Fire Department who provided consultation in the development of this system. In order for the application to carry the weight that was desired for fire safety training, it had to effectively mimic a real fire situation.

There are a few important implications of this requirement. First of all, this means that the smoke must be generated in a realistic way from the starting point of the fire. Secondly the smoke must continue to fill the room in layers from the ceiling as it does in reality. In addition the whole process must happen very quickly, as smoke can often fill an entire room in a matter of seconds (Pehrson, 2004). Finally, the smoke needs to be dense enough to obstruct the view of anyone who is standing in the middle of it so that the participants are forced to crawl if they want to see where they are going. Figure 1 shows

Figure 1: Layers of Smoke
layers of smoke descending from the ceiling. To handle this requirement a particle system would have to be used to simulate smoke in the virtual environment.

In addition this particle system would have to be thread safe to work on a clustered system. OSG’s particle system is not thread safe and in addition does not work well inside VRJuggler. As a solution, the Particle System API (www.cs.unc.edu/~davemc/Particle) was integrated into the application. This open source particle system is thread safe and features an API similar to that of OpenGL (McAllister, 2000). In general smoke behaves according to the laws of fluid dynamics, this can be very hard to simulate properly and when implemented requires a great deal of processing power. In this case it is less important that the smoke behave like real smoke than that it look like real smoke.

With this in mind, a separate class was created to handle particle systems. The main application creates each system and defines position and movement variables for each system. It then tells the particle system handler to create a particle system with the previously defined variables. The Particle Systems API allows for the creation of action lists, which define a series of behavior action calls that are optimized to run as a group on a given particle system. In much the same way an OpenGL display list can be used to quickly draw complicated figures, these action lists make simulating each particle system more efficient and reduce the computational load on the system. Once each particle system has been defined they are ready to begin simulating. The main application checks to see which particle systems are on at the beginning of each frame, an update call is sent to all active particle systems.

Particle systems are represented internally by an array of points. To draw the particles as puffs of smoke a function was added to the particle handler class to draw each point in a given particle system as an OpenGL quad. The smoke texture is then mapped to the drawn quad and a cloud of smoke begins to form.
3.2 Game Development

The “game” is defined in two distinct parts here, a timed hazard search and an evacuation from a simulated fire event. The evacuation is the most important part of the experience as it represents the actual physical practice that users get during this training exercise. Physically acting out a procedure often makes it easier to remember (Randall & Jones, 1993), therefore forcing users to act out an actual physical escape, while crawling, from the fire scene was very important. The difficulty with this goal in the context of a game is that, if done correctly, escaping from the fire will take less than a minute. This does not lend itself well to an interactive VR experience that the user will remember in the future or to any sort of entertainment value. Therefore we added a separate task to the VR game, a search for fire hazards.

Identification of fire hazards is something that fire departments like to stress with children, it keeps them away from dangerous items, such as candles that may hurt them, and it can stop a fire before it starts. Both the NFPA and the USFA maintain a version of a home hazard search on their children’s sites, the hazard search was modeled based on these applications and on input from firefighters. The hazard search game was developed from a list of common home fire hazards provided by the Ames Fire Department. The following sections describe the details of the development of the game.

Figure 2: Logitech Wireless Gamepad
3.2.1 Navigation

This system needed to appeal to a demographic whose experiences with technology frequently include video game systems with high-end graphics ability. Prior research with games designed for education shows that the intended user often expects a great deal from an application this is referred to as a “game” and is then disappointed by the application that is presented (Elliott, Adams, & Bruckman, 2002). With this in mind, the game-based version of the fire safety application was designed to be as interactive as possible. This includes allowing the users to navigate their environment dynamically, necessitating some form of

Figure 3: Common Fire Hazards
collision detection that would prevent users from passing through objects in the virtual environment.

OPAL was integrated into the visual simulation by creating physical representations of all the important objects in the virtual environment. The user is represented by an invisible sphere, subject to the effects of gravity, and their movement is powered by an OPAL motor. The terrain of the Fire Safety environment is composed of a single model. This includes the ground, the house and most of the furniture. As a result this is a very complicated model that cannot be easily represented by the primitives provided by OPAL. In cases like this OPAL provides for the definition of a mesh object. Mesh objects are defined by an array of vertices and a second array that defines which vertices represent which triangles. The more vertices that are defined, the more complicated the final mesh, and the more computational resources it requires to compute collisions each frame. To keep the amount of work to a minimum the visible model was simplified in a modeling application so that complicated objects like a dining table were represented by cubes whenever possible, and some small objects that would not impact player movement, such as ashtrays on tables, were removed from the physics model entirely. This allowed for a much simpler and less computationally expensive physical representation of the virtual space without losing any interactivity.

Players control their motion using a gamepad, like the one shown in Figure 2, the right analog stick is used to rotate the players view and the left analog stick is used to move forward, backward, side to side and any combination there-of. Forward is defined by the direction the player is facing when they move the analog stick. This allows the user to face any wall of the immersive environment without having to adjust the way they are using the gamepad. The gamepad is an intuitive choice for navigation because this kind of navigation technique is a standard input method for video games.
3.2.2 Hazard Search

Hazard removal presented a unique challenge in terms of information sharing. Each hazard must be represented by a visual model, to be removed when the hazard is discovered by the

Figure 5: Completed house model viewed from outside.
user; this is not complicated as most scene graphs provide some functionality for switching a
node on and off. However, each of our hazards must also be physically represented so that
the user cannot pass through a hazard until it has been removed from the environment.
Therefore, both the visual simulation and the physical simulation must maintain a
synchronized list of hazards and update this list as hazards are removed. The scene graph
passes the positions and sizes of the hazard models that load to the physics simulation at
runtime. The physics simulation constructs a physical representation for each hazard, this is
in most cases a sphere, and then indexes them so that they are aligned with the list in the
scene graph. When the user attempts to identify a hazard by indicating it in the application,
the scene graph queries the physics simulation, which checks for successful identification
and passes an index back to the scene graph of the hazard model that needs to be removed, if
any. Figure 4 shows the information flow that occurs to support this function.

In order to have a fun way to indicate hazards in the virtual environment an interface
was developed using a six degree of freedom wand. The user points the wand at whatever
item they wish to remove. The wand includes a tracker that reports it’s orientation in the
CAVE, this orientation information is passed to the physics simulation which fires a ray in
the direction the wand is pointing. If a hazard model was hit, meaning the first thing the ray
encounters is a viable hazard model, the hazard is marked as found and the physics
simulation reports the index of the discovered hazard back to the visible simulation. The
hazard model is then removed and a sound is played to indicate the successful identification
of the hazard. Examples of the hazards implemented in this application are shown in Figure
3.

3.2.3 Fire Evacuation

Much current fire safety training focuses on a bedroom scenario because many of
the most dangerous house fires occur at night when occupants are asleep (Jones, Kazdin, &
Haney, 1981). However for our purposes a bedroom escape is unrealistic because transferring the necessary skills would be difficult in a virtual environment. In the case of a bedroom fire a person must feel the door of the room and then look out to gage the smoke in the hallway, neither of these activities transfers well to virtual space, therefore a different scenario was necessary in this application. The kitchen, is a viable place for an escape, the only necessary escape skill is crawling which does transfer well to the virtual environment making this a fairly realistic situation. In addition the most common area in a house for a fire to start is the kitchen and cooking fires are the most common type of residential fire (United States Fire Administration, 2002), so this is a relevant situation. Figure 5 shows a view of the house model from the outside. The red mailbox is defined as the meeting place where users should go when they escape from the house. A smoking pan was added as one of the fire hazards and when time runs out in the hazards search users are instructed to find the kitchen. The kitchen fire begins at the stove and spreads out through the room. In order to create this effect several particle systems were used in tandem. First a small system that released puffs of smoke at large intervals was added to show that the food left on the stove was burning. Then a larger, faster moving plume of smoke was created which would be turned on once the fire started. This plume was shaped like a funnel and moved up and out from the source of the fire. Once this smoke reached the ceiling of the room a layer of smoke was animated to begin to roll across the ceiling away from the source of the fire. A second later another layer starts and this continues until the final layer begins, this lowest layer is approximately 3 feet from the ground. After the first layer of smoke starts a fire alarm begins to sound. The users must crawl to be able to see where they are going in the virtual environment.

This lowest layer is approximately 3 feet from the ground. The CAVE is view-dependent, meaning that if the users stand up moving their viewpoint above the smoke ceiling, they will see nothing but dark heavy smoke. However, if users crawl close to the
floor, they can see their surroundings and see a way to escape. Following their escape from
the kitchen users are instructed to go to a pre-defined meeting place. Having a meeting place
is one of the most important safety tips offered by fire fighters. This will encourage users to
think about where the meeting place is outside their own home and the layered smoke will
drive home the point that it is vitally important to crawl if one finds themselves in a fire
situation.

3.2.4 Interface

One of the central complaints of participants during the pilot test was that they
wanted to explore the virtual house on their own. Children seemed to be especially frustrated
by merely being passive observers of the VR technology. When designing the interface and
game play for the new game-based fire safety application we wanted to take this into
account. This led to the implementation of the gamepad for navigation, a simple interface for
our intended age group of 8-11 years old. Another theme we saw from the results of the first
experiment was that many children were nervous about entering the virtual environment.
Many asked if they would be able to bring a friend with them, with this in mind the interface
was designed to accommodate, and in fact require, two participants. Previous work suggests
that if two children are using an application together it is important that each have an
important role so that they are forced to collaborate (Ohlsson, Moher, & Johnson, 2000). In
the fire safety application one child is the Navigator, they use the gamepad a wear the tracked
stereo glasses. The other child is the Hazard Zapper, they use a 6DOF wand and a pair of
non-tracked stereo glasses, and are responsible for the removal of hazard models as shown in
figure 6. This “laser” technique is very popular when working with object selection in 3D
VR environments (Vanacken, Grossman, & Coninix, 2007). In this way the children must
communicate in order to effectively eliminate fire hazards, in addition they never have to be
alone in the virtual environment reducing their anxiety about the experience.
Figure 6: Users zap a hazard in the VR game

Figure 7: HUD display during fire evacuation
A heads up display (HUD) was added to the application to provide users with information now that there would no longer be a firefighter assisting them in the environment. The HUD displays instructions and information the walls of the CAVE so that the information is accessible to the user whatever direction they are facing. Figure 7 shows a screen shot of the HUD during simulated fire evacuation. Figure 8 shows the HUD at the end of the game when users reach the meeting place.

4. User Study

The following sections describe the development of the fire safety training program and the testing procedure.

4.1 Participants

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<th>10 - 11</th>
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<tbody>
<tr>
<td>Participants</td>
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Table 1: Age distribution

Participants were drawn from area Boy Scout troops. Table 1 shows the age distributions in our study. There were 21 participants total and their ages range from 7-11.
Requirements for our participants included, being able to read and write proficiently and no prior VR fire safety training experience.

### 4.2 Training Procedure

Children were trained in groups no larger than ten students, taking turns children played the VR game in teams of two. Participants are first given a tour of the VR equipment so that they are familiar with the technology being used. This information also facilitates discussion about how the game will work and explaining the interface later in the training session. After the participants have seen the VR equipment they are taken to a classroom and a fire safety pre-quiz is administered to gage the participant’s baseline level of fire safety knowledge. A video is shown of a firefighter giving a presentation designed to give the children a framework for thinking about the fire safety application. After the video a short presentation is given, that describes the interface of the game system and explains what the objectives of the game are. Participants use the VR application in teams of two; the control group takes a post-quiz prior to using the VR application while the experimental group uses the VR application first and then takes the post-quiz. Figure 8 shows a flowchart outlining the steps in the training process, the experimental group is denoted by the dashed line and the control groups steps are shown by the solid line.

![Flowchart showing experimental process](image)
4.3 Experimental Results

Results were analyzed for data collected from both the quizzes and the user experience survey that were administered. Of the 22 participants that took the quizzes one did not fill out a survey so there were only 21 data points when analyzing the survey responses.

4.3.1 Pre- and Post-test

The quiz that was provided to participants to measure their learning was developed based on the main points communicated in the fire safety presentation given by the fire department in the video we created. It is composed of five fill in the blank questions, five true or false, and an open ended section that asks students to think of some fire hazards, and describe the first thing they would do if they were in a room that was filling with smoke. Students’ pre-test and post-test scores were recorded and analyzed. The means of the pre-test and post-test scores are shown in figure 10. The difference is significant, indicating that some learning did occur as a result of the program. However when the results are separated into students who took the test prior to experiencing the VR application and those who took it after, no significant difference is seen between the two groups. Figure 11 shows the results of

![Figure 10: Mean scores for Pre- and Post-Test](Image)
testing when the population is divided into experimental and control groups. Table 2 shows the results of a matched pairs test that was carried out on the general pre- and post-test data indicating a significant improvement.

4.3.2 Survey results

The surveys asked students to describe their experiences in the CAVE; the distribution of this data can be seen in figure 8. The survey asked participants to rank the amount they felt they had learned on a scale from 1 to 5 with 5 being the highest, Next subjects were asked how frightened they felt in the CAVE on a scale of 1-5 with 5 being very frightened, and then how easy it was to play the game 1 being very hard, and 5 very easy. Figure 12 shows the distribution of responses to these questions. We discovered a significant difference based on
the age of the participants in how frightened they were in the virtual environment with 10 year olds reporting significantly less fear than 8 year olds in the study. Table 3 shows the results of this analysis.

The final part of the survey asks for the user’s opinion of their most and least favorite parts of the program. There were some obvious groupings in responses to the other two questions. Figure 13 shows participants responses to what they liked best in the training program, the most popular being getting to play the game. Figure 14 shows the responses to what participants liked least during the program. There are also some patterns in these responses; frustration over the hazard zapping functionality was the most popular response. There were also several responses indicating that participants felt dizzy or sick while using the VR application.

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Table 2: Matched Pairs: Difference Post-Test - Pre-Test
5 Discussion

While the level of learning was not significantly different for the experimental group, it is important to note that their scores started at a higher level. This was an unintended result, participants were allowed to pick their own groups and order in which they used the application. The quiz was designed to be short and simple so that children aged 8-11 would be able to complete it. With only sixteen questions, some participants who scored very well on the pre-test did not have much room for improvement on the post-test and this may have affected the results. Although there was no statistical evidence supporting the use of the immersive VR, it is important to note that the scores of the experimental group are higher than the scores of the control group and perhaps further testing would indicate a greater difference. It may also be possible to get a better idea of the information children are gaining from this program by changing the testing procedure, the quiz being very simple may not reflect the higher learning outcomes of the training program. An interview evaluation format may yield more representative results. In addition to testing outcomes, there were several interesting observations that came from the program.

### Table 3: Statistical results comparing fright and age.

<table>
<thead>
<tr>
<th>Level</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 - 8</td>
<td>A 3.6250000</td>
</tr>
<tr>
<td>9</td>
<td>A, B 3.000000</td>
</tr>
<tr>
<td>10 - 11</td>
<td>B 1.5555556</td>
</tr>
</tbody>
</table>

Levels not connected by same letter are significantly different.
Figure 13: Responses for "What did you like best about Fire Safety Training?"

Figure 14: Responses for "What did you like least about Fire Safety Training?"
5.1 Zapping Complications

The noise associated with the tracker hardware makes it difficult to aim at hazards in the environment, especially when pointing at objects that are far away or not at right angles to the user. This imprecise targeting was frustrating for the young users of the system. To alleviate this problem the internal logic for checking for hazard identification was improved. In addition to the ray that was used to check for intersections, a box was added in the same orientation and length as the ray and then checked for intersections. This allows for a certain amount of error in the tracker readings on the wand, and makes it easier to select hazards. Unfortunately, there is still a certain amount of error associated with the wand tracking that cannot be eliminated.

Six participants said that the problems with hazard zapping were their least favorite part of the whole experience. This constitutes more than 25% of our population and seems especially large considering that only half of the population would have had a chance to interact with the zapping functionality. In addition several students mentioned zapping as one of their favorite parts of the VR experience, demonstrating that this kind of interaction is compelling for young users.

5.2 User Experience Observations

One surprising issue that was encountered was getting the children to crawl in the virtual environment. The head tracking software adjusts the camera view when the navigator kneels, allowing the users to see below the layers of smoke that have formed. This is an aspect of the virtual environment that we believe makes it especially useful for training this particular skill, however many of the children were confused by this idea. Even after they were instructed to get on their knees they sometimes did not make the connection. One child asked “How do I kneel?” This was an unexpected user interface issue, in that children who
are used to playing video games can talk about doing an activity without actually expecting to have to engage in the activity.

Younger children reported feeling more fear in the virtual environment; this indicates a greater level of immersion and a more powerful learning experience. This may lead to greater learning gains over time for younger children. We don’t want to traumatize children during fire training; however a proper level of realism is necessary for safety training. Younger children also had a greater problem with feeling dizzy or motion sick. These observations suggest it’s possible that this younger population is better served with a modified version of this training process that involves less waiting and larger groups using the application at a time.

In spite of the frustration associated with hazard zapping most of the users enjoyed the experience. All participants were very excited once they were able to start playing the game. Most remarked that it was just like being inside a video game. This enthusiasm for what is relatively standard fire safety information is encouraging as it demonstrates the promise of VR for training vital but tedious skills.

6. Conclusions and Future Work

Fire safety is a difficult skill to evaluate because children need to be able to reproduce correct behaviors under highly specialized condition of a fire situation, demonstrating correct behavior in a classroom setting does not necessarily translate to real-world situations. VR applications show promise for providing the ability to train skills like fire safety in the dangerous situation where they will be necessary.

The program would benefit from the development of a separate procedure for younger children. Unfortunately, younger students had a harder time completing the quiz and became more frustrated with the forms that they had to fill out as part of the study. For younger children an interview evaluation format would be even more beneficial.
everything that they understand can be difficult for them. In addition an intelligent agent would be an interesting addition as a training guide. The game-like elements could be improved upon by making hazard placement dynamic, so that hazards would not show up in the same locations on successive runs of the program. This functionality would make the game interesting for repeated training as users would not know where all the hazards are located.
CHAPTER 4. SUMMARY AND DISCUSSION

The fire safety project is an attempt to make fire safety skills fun to learn. VR has been leveraged to create an interactive training environment. In the first iteration children were accompanied through the simulation by both a firefighter and a student navigator. While this helped keep children motivated and perhaps helped frame the fire safety message because a qualified instructor led the group through the activity, it also frustrated many children who wanted to be able to explore the environment on their own. To address this issue the second iteration, a game-based version of the fire safety application was designed to be playable without the help of a graduate student navigator, or a firefighter. This provides users with a more immersive experience and makes them active participants in the learning process. However it also means that students are left to discover appropriate procedures for themselves, for example in the past when the virtual room was filling with smoke, the firefighter could instruct children to get close to the floor, and the student navigator controlled the head placement in the virtual environment so the view was adjusted to closer to the floor for students. In the newer version of the application the students themselves must figure out the crawling low will help them see. In addition the open nature of the VR facility seems to encourage children to talk to the other people in the room and parents to answer. This added interaction may skew testing results but may also add to the learning experience for the users.

Using the immersive game-based application as part of a fire safety training program did not statistically increase the learning gains of the participants. However, since students came to the program knowing that they would get to play a VR game it is possible that they were more focused on the fire safety message because they were excited about the new technology. The program as a whole did add to participants prior understanding of fire safety procedures.
4.1 Future Work

The Fire Safety Project would benefit from an examination of the way hazard zapping is handled. While the current method works better than the original implementation it is still difficult and frustrating for users. In addition the hazard identification game could be improved by scripting several possible locations for each hazard and assigning them at random so that hazards do not show up in the same location on successive runs of the program. The fire escape scenario could be expanded to include more locations, possibly not starting from a hazard that has been removed from the environment. Adding an intelligent agent to the application may do a better job of replicating the experience of having a firefighter as a guide without the frustrations associated with passive observation of the environment. Fire safety is a difficult skill to test in children because they may not ever need the skills and if they should find themselves in a fire emergency they either are prepared or they are not. Hopefully those children that participated in this program are better prepared in the case of a fire event in their home; the immersive VR experience is not one that children are likely to forget.
APPENDIX EVALUATION INSTRUMENTS

This Section contains the survey that was used in the first implementation of the Fire Safety project. Following that is the quiz that was used to evaluate each student’s fire safety baseline and what they had learned during training in the second iteration of the project. Also included is the survey that was used during that program.
Fire-Safety Virtual Training Survey

1. Gender
   - [ ] Girl
   - [ ] Boy

2. What is your age?

3. How much you learned about fire safety during this training program? (1: nothing at all, 5: a lot)
   - [ ] 1
   - [ ] 2
   - [ ] 3
   - [ ] 4
   - [ ] 5

4. Did you ever feel frightened while in the fire scenes in the CAVE? (1: not at all; 5: a lot)
   - [ ] 1
   - [ ] 2
   - [ ] 3
   - [ ] 4
   - [ ] 5

5. Circle the words that describe how you felt during the training in the CAVE.
   - [ ] Sad
   - [ ] Happy
   - [ ] Nervous
   - [ ] Interested
   - [ ] Scared
   - [ ] Excited
   - [ ] Sick
   - [ ] Dizzy
   - [ ] Fun
   - [ ] Awesome

6. Circle the types of fire safety training you have had.
   - [ ] Talk with Pictures
   - [ ] Video or TV
   - [ ] Reading a Book
   - [ ] Virtual Reality CAVE
   - [ ] None of them

7. Which of the following fire safety training approaches do you like best?
   - [ ] Talk with Pictures
   - [ ] Video or TV
   - [ ] Reading a Book
   - [ ] Virtual Reality CAVE
   - [ ] None of them
8. What was the most importance thing you learned in the fire safety training program today?

9. What do you like the most about fire safety training in the CAVE?

10. What do you like the least about fire safety training in the CAVE?
Fire Safety Quiz

Directions: Complete each sentence.
1. What is the most common type of household fire? ________________
2. ________________ is the time of day when most cooking related fires happen.
3. It is important that you have working _______________ detectors in your home.
4. Most house fires take place in the ________________.
5. Never use the ________________ to go downstairs during a fire.

Directions: Read each statement. Decide which statements are true and which statements are false.

T    F    1. You should have an escape plan, but it is okay not to practice.
T    F    2. Your family should have a meeting place a safe distance from your home.
T    F    3. It is important to know how to operate all windows and doors in your house.
T    F    4. It is okay to only know one way out of a room in your house.
T    F    5. Floor coverings can help you navigate in a room filled with smoke.

List 5 examples of fire hazards.
1. ________________
2. ________________
3. ________________
4. ________________
5. ________________

If you are in a room that is filling with smoke what is the first thing you should do?
Fire-Safety Training Survey

1. Gender
   □ Girl  □ Boy

2. What is your age?

3. How much do you think you learned about fire safety during this program? (1: nothing at all, 5: a lot)
   □ 1   □ 2   □ 3   □ 4   □ 5

4. Did you ever feel frightened while in the fire scenes in the CAVE? (1: not at all; 5: a lot)
   □ 1   □ 2   □ 3   □ 4   □ 5

5. How easy was it to use the VR application? (1: very hard; 5: very easy)
   □ 1   □ 2   □ 3   □ 4   □ 5

6. What was the most important thing you learned in the fire safety training program today?

7. What did you like the most about fire safety training in the CAVE?

8. What did you like the least about fire safety training in the CAVE?


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