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Fire safety and emergency evacuation training for occupants of building using 3D virtual simulation

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FIRE SAFETY AND EMERGENCY EVACUATION TRAINING FOR OCCUPANTS OF BUILDING USING 3D VIRTUAL SIMULATION

by

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ABSTRACT

With advancement in technology, building structures are becoming bigger and more complex. Incidences of horrifying fires that occur in such complex structures resulting in loss of property as well as lives are recorded worldwide. Emergency evacuation training can play a crucial role in mitigating damage not only in cases of fire, explosion or chemical spill but also in cases of natural calamities like floods and hurricanes. Conventional safety training provided in industries mostly comprises of unidirectional flow of information. Due to this passive learning style, response of employees in real life emergency situations is known to be ineffective. The proposed research focuses on the development of virtual emergency evacuation safety training for residents, workers and employees.

This research developed a 3 dimensional (3D) virtual fire safety and emergency evacuation training for building occupants. A 3D model of a real engineering college building in the University of Central Florida (UCF) was developed in a virtual world and participants could interact with various objects and scenarios in this virtual building on a standard desktop computer using keyboard and mouse. Expert interviews and literature review were utilized to develop contents of fire safety and emergency evacuation training. Also, a slide based fire safety and emergency evacuation training was developed based on same contents and made available through a website. An effort was made to develop both trainings- virtual and slide based to be comparable in terms of contents. A case study with two sets of experiments comprising of 143 participants from UCF community was conducted to understand factors such as fidelity, simulation sickness, engagement and effectiveness of 3D virtual and slide based fire safety and emergency evacuation

training. Results of fidelity and simulation sickness validated use of 3D virtual training for training building residents on fire safety and emergency evacuation. Data analysis of knowledge tests allowed to compare short terms and long term effectiveness of 3D virtual training and slide based training. To further understand engagement, physiological measure- electroencephalograph (EEG) of 40 healthy participants was recorded in second set of experiments. Ratio of Beta and Alpha frequency bands was studied to understand attention paid by trainees in 3D virtual and slide based training.

This dissertation is dedicated to my husband, *Narendra Shiradkar*, without whom I would have never embarked on this journey

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LIST OF ABBREVIATIONS

BLS - Bureau of Labor Statistics
CAD - Computer Aided Design
CAVE - Cave Automatic Virtual Environment
CFD - Computational Fluid Dynamics
DOF – Degrees of Freedom
ECG - Electrocardiogram
EEG - Electroencephalogram
EHS - Environmental Health and Safety
GSR - Galvanic Skin Response
HMD – Head Mounted Display
ICA – Independent Component Analysis
LSL - Linden Scripting Language
LVC - Live, Virtual and Constructive
NFPA - National Fire Protection Association
OSHA - Occupational Safety and Health Administration
PASS- Pull, Aim, Squeeze, Sweep
PHP - PHP: Hypertext Preprocessor
PPT- Power Point Training
PST - Pacific Standard Time
SBT - Simulation Based Training
SSQ - Simulation Sickness Questionnaire
SWOT - Strength, Weakness, Opportunity and Threats
VE - Virtual Environment
VR- Virtual Reality

CHAPTER 1 INTRODUCTION

1.1 Background

On June 7, 2015 fire broke on the 14th floor of 21 storied building in Mumbai, India. It claimed life of 7 residents and left 25 residents injured. It became difficult for firefighters to navigate inside the building to help residents as staircase was blocked with goods. Residents panicked when fire broke and five residents entered elevator which lost electric power supply rendering these residents unconscious ("Mumbai: 2 fires in Bandra, Powai leave 7 dead, 28 injured," 2015). Structural fires resulting in loss of life and property damage are often reported worldwide. Some of the examples are - footwear factory in Philippines caught fire which killed 72 workers (Mullen, 2015), Rhode Island nightclub fire resulted in 96 deaths ("At least 96 killed in nightclub inferno," 2003), fire in 28 story building of Shanghai killed 58 people and injured 70 residents ("Shanghai high-rise fire death toll rises to 58," 2010).

There are also incidences of fires reported in and around universities. From year 2000 to 2015, 118 fatalities are reported from 85 fires that started in dormitories, fraternities, sororities and off-campus housing. Smoke alarms were not present or were not working in 58% of these fatal fires and sprinkler mechanism was missing in all 85 cases (Administration, 2017). Fire that broke in 2015 in apartment complex near University of Central Florida displaced 75 residents, including 25 university students (Poggio, 2015). Explosion that occurred in 2010 in Texas Tech is another example of such horrifying university accident ("Investigations," Oct 19, 2011).

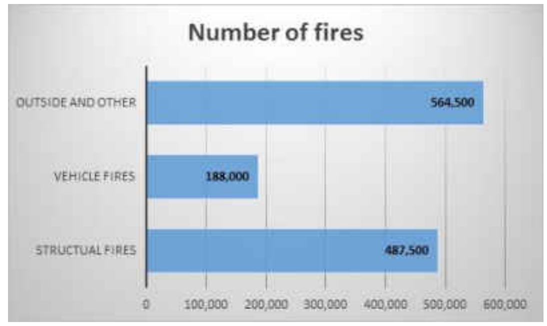
With advancement in technology, building structures are becoming taller and more complex. Thus, evacuation of occupants of a building in case of emergency situations that involve not only fire but also natural disasters like flood and hurricane has become a global issue. Many building residents lose their lives because they are not aware of the do's and don'ts of emergency situations. Building residents as well as workers and employees need to be trained on emergency evacuation. United Nations has urged a global action to make workplaces safe after the factory accident in Philippines ("In wake of deadly shoe factory fire in Manila, UN urges global action to make workplaces safe," 2015).

1,240,000 fires were reported in United States alone in year 2013 resulting in 3240 deaths and property loss of 11.5 billion dollars. Out of those fires; 487,500 fires were structural fires which claimed 2855 lives and property damage of 9.5 billion dollars (NFPA, n.d.).

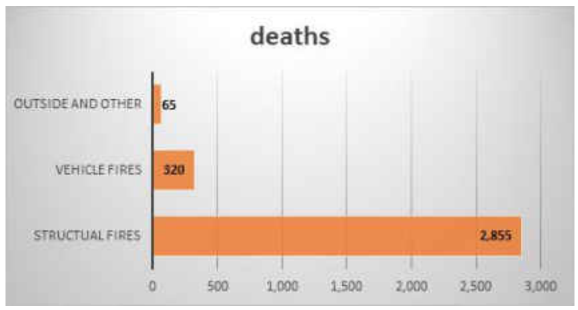
As shown in figure 1-1, structural fires are majorly responsible for deaths, property damage and in injuries. From these statistics, it is apparent that safety training is crucial to reduce fatal and non-fatal injuries due to emergencies along with the costs associated with them.

Though safety training can help reduce rate of illness and injuries, many accidents and unfortunate events are observed to be the outcome of inadequate safety training. Inadequate safety training can be defined as the situation where a) Safety training is not provided, b) safety training is provided but is not internalized by people and thus not reflected in behavior at workplace environment, and c) safety training is provided but in ineffective manner (Blair & Seo, 2007).

(a) Property damage due to fires in 2013



(b) Number of fires reported in 2013



(c) Number of deaths reported in 2013

Figure 1-1 Statistics of fires reported in U.S. during 2013

Burke et al. (2006) performed a meta-analysis study of research conducted between 1971 to 2003 in 15 different countries to determine relative effectiveness of three types of methods used in health and safety training – least engaging (lecture, video), moderately engaging (programmed instructions) and most engaging (hands on or behavior modeling). The results depicted that all methods of training improved performance of employees to certain extent. However, it was observed that the number of workplace injuries and accidents were reduced as methods of training became more engaging.

There are 2 modes of safety training that are used most commonly by industries

1) Lectures delivered by a safety subject matter expert in a classroom

2) Videos or slides provided to employees on personal computers

However, due to unidirectional flow of information, employees involved in such training are not actively learning. Hence, their response to understanding risks and mitigating them in real time workplace emergency situations is not as subjective. Human learning process comprises of gathering information, organizing and applying it to the surrounding environment to gain the feedback and convert lessons learnt from this process into knowledge that can be retrieved as and when required in future events (Bhide et al., 2015). The training that provides trainee an opportunity for two-way communication is thus immensely valued.

With the advancement in technology, people are becoming more adept at computer and phone based video games, virtual reality and web based applications. Simulation based training (SBT) allows to develop 3- dimensional (3D) environment where one can model entities such as furniture, buildings, offices and even cities from real life. Avatar of a trainee can interact with different objects by simply utilizing computer keyboard or mouse. Trainee can choose avatar's accessories such as clothes, skin, body shape, hair and shoes to give it similar looks as of trainee. Due to capability of interacting in a world that imitates real world, trainees feel as if they are present in real environment while utilizing 3D simulation based training. In virtual world, trainees interact with virtual objects, receive feedback and shape their decisions based on it. Simulation based training allows to log behavior and response of trainees that can be used at a later stage to provide feedback. Therefore, this training allows and shapes dynamic decision making of trainees. In some situations, such as fire or chemical explosion. it is difficult to test knowledge or learning in real time scenario because they could be too risky for the subjects. One of the major reasons behind using virtual constructive simulations for emergency evacuation training is that it allows to safely introduce trainees to risky scenarios. Also, SBT helps to overcome language barrier and provides an environment for practicing skills.

Researchers and industries have identified advantages and the important role that virtual SBT can play in safety education. However, costs associated with development and implementation of virtual simulation based training is one of the aspects that is affecting its ubiquitous presence in the safety training. Also, most of the researchers are interested in development of virtual simulation environment and its user experience. They hardly offer multiple player or social interaction aspect to the virtual environment which could be important factor shaping behavior of participants in case of emergencies. Also, evaluation of simulation based training for evacuation safety is rarely performed rigorously to establish it as an effective tool for training. In addition, it is important to identify the level of engagement that trainee experiences in simulation training. Hence, there is a need for a system for safety training development that can tie different aspects of simulation based training together to make it a viable option for training residents and workers on emergency evacuation.

1.2 Problem statement

Industries conduct safety trainings majorly utilizing lectures, newsletters or slides. However, these training techniques lack visualization and interaction aspect. Thus, they rarely make employees or common people aware of various safety related risks, identifying them in surrounding environment and what are the actions to be taken in case such an emergency occurs. Some industries like defense industry and aviation industry are using virtual simulation based training which is interactive, immersive and risk- free to help improve skills of soldier trainees. On the other hand, industries like healthcare, manufacturing and construction have been working on development of virtual simulation based training for teaching industry specific skills. It was identified that there is a need for a better safety training system for emergency evacuation that will have methodology for evaluation of training effectiveness, engagement and transfer.

1.3 Research objectives

The objective of this research is to develop a 3 D virtual fire safety and emergency evacuation environment that will have different layers such as content creation, 3D virtual model development, user interface, data logging, feedback method and validation. This system will act as a basis for development of virtual simulation based emergency evacuation safety training for residents of buildings where they can visualize and interact with various fire safety scenarios. Once the virtual fire safety and emergency evacuation training is developed, it will be compared with a conventional training mode like slide based training to understand factors such as effectiveness and engagement. Using electroencephalogram (EEG) as a physiological measure, neural signals of participants will be recorded during training. Ratio of power in Beta and Alpha frequency bands of EEG will be studied to understand level of attention and focus of participants in 3D virtual and slide based training.

1.4 Scope and limitations

This research considers development of 3D virtual simulation to be displayed on personal or desktop computers for fire safety and emergency evacuation training of residents of buildings. It does not address virtual environment development that is utilized for driving simulators and flight simulators. We are strictly focusing on safety environments for buildings. This research is trying to establish a system for developing simulation based fire safety and emergency evacuation training. This research does not claim that SBT is an alternative for other existing methods such as fire drills or field studies. In fact, it can act as an aid to hands-on training activities.

1.5 Organization of chapters

Chapter1 provides background to the emergency situations resulting in loss of life and property damage. Importance of emergency evacuation training for common public, employees and workers has been introduced along with the role of virtual simulation based training. Need for development and evaluation of simulation based fire safety and emergency evacuation training has been explained along with research question and scope. Simulation based training, SBT, virtual fire safety and emergency evacuation training, 3D virtual fire safety training these terms are used interchangeably for 3D virtual fire safety and emergency evacuation training proposed in this work. Slide based fire safety and emergency evacuation training is referred as Power point based fire safety training, slide based training, conventional slide based training and information based training.

Chapter 2 provides a detailed literature review performed to understand various aspects of simulation based training and emergency evacuation training. First different methods of safety training are explained. Then, how 3D simulations are utilized in different industry sectors, what is live-virtual-constructive simulation, and the need of 3D emergency evacuation training are explained. This chapter also elaborates on research done on emergency evacuation, required features of 3D simulations and evaluation methods for 3D simulation based training. The last section of this chapter identifies the literature gap that will be explored in this research.

Chapter 3 describes research methodology, which maps scientific method of conducting experiments for this research. This chapter explains participants, procedure, research design and statistical analysis method employed for experiment 1 and experiment 2.

Chapter 4 explains framework of development of 3D virtual and conventional slide based fire safety and emergency evacuation training. It also describes content developed based on literature and expert interviews.

Chapter 5 presents details of EEG instrument, data collection, data processing and analysis of neural signal data into different frequency bands of interest such as alpha, beta, gamma.

Chapter 6 has results of experiments. Results are explained as 1) conventional fire safety training results, 2) 3D virtual simulation based training results 3) comparison of conventional and 3D virtual fire safety and emergency evacuation training 4) comparison of engagement felt in virtual and conventional training using EEG.

Conclusions and future work for this research on 3D virtual training development of emergency evacuation and fire safety is summarized in chapter 7.

CHAPTER 2 LITERATURE REVIEW

2.1 Health and safety training methods

According to Friend and Kohn (2014), till 2007 an average of 5000 workplace injuries were observed every year on the job. It is estimated that approximately 95% of all workplace accidents can be avoided by the actions of either employee, supervisor, manager, and/or corporate level (Jin & Nakayama, 2013). Safety training is considered as an important aspect that can help reduce occupational injuries and illnesses. As shown in figure 2-1 (adopted from (Bhide & Rabelo, 2015)), there are four methods commonly used in safety training: 1] Information based, 2] computer instruction based, 3] hands-on activities, and 4] simulation based. This section provides overview of various health and safety training methods used in industries

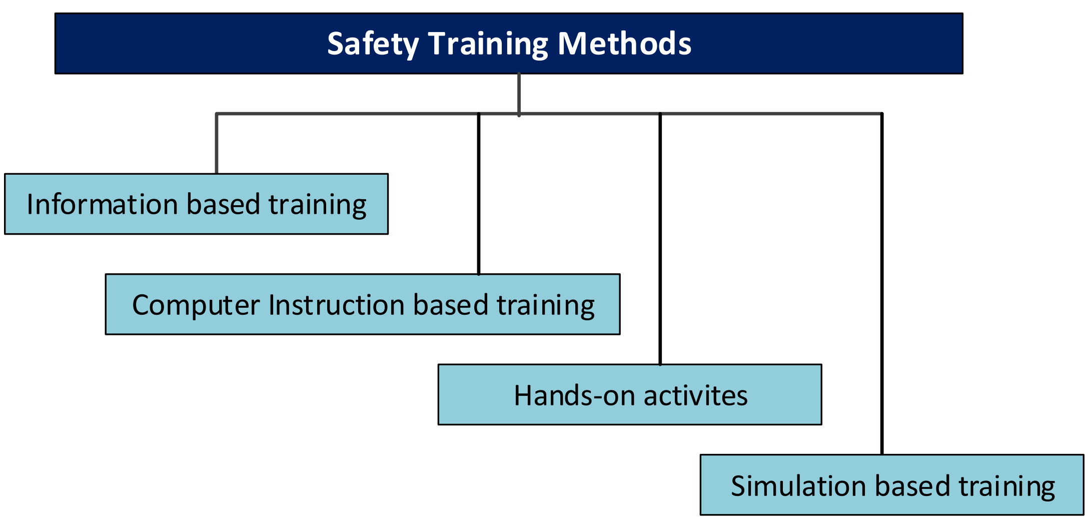


Figure 2-1 Commonly utilized health and safety training methods

2.1.1 Information based training

This is the most commonly utilized method of providing information to trainees. In information based training, trainer or a subject matter expert conveys information to trainees through speech where power point slides or videos are utilized as training aids in classroom type setting. This process involves unidirectional flow of information from trainer to trainee (Laberge, MacEachen, & Calvet, 2014). Occupational health and safety awareness approaches emphasize on developing attitude or behavior of employees towards understanding and following rules (Burke et al., 2006), i.e. these efforts are directed more towards trainer's role resulting in unidirectional knowledge exchange from trainer to trainee. Hence, this type of training is considered as least engaging mode of training. This method is considered to have tendency of turning trainees into passive learners (Herr et al., 2016) and to emphasizes more on teaching process rather than leaning process (Laberge et al., 2014). Information based safety training is considered cost effective as multiple people can be trained at one location and most of the cost is associated with trainer ("The Most Effective Training Techniques," n.d.). Thus, information based training needs less infrastructure and resources but trainees are less actively engaged in the learning process.

2.1.2 Computer instruction based training

This training mainly includes slides with some images, video and audio capabilities to present information in standardized format on a personal computer. An advantage of computer based instruction method is that it is convenient and portable method of providing knowledge to employees (Horton, 2000). Computer instruction based training is used by most organizations to train employees on variety of topics as it removes need of hiring a professional training staff. It allows employee to undergo safety training using a personal computer irrespective of constraints of time and location (Chait, n.d.). This training method is cost effective but does not involve interaction. Thus, safety training received with computer - based instruction becomes a passive leaning experience (Bhide et al., 2015).

2.1.3 <u>Training with hands on activities</u>

It is observed that employees develop skills not only through self-learning and their own actions but also by learning through contact with other employees and co-workers (Laberge et al., 2014). Training with hands - on activities method engages trainer and trainee in a dialogue regarding knowledge acquired or application of that knowledge in a specific situation. In this type of training, instead of trainer teaching trainees, trainees learn safety practices through hands - on activities and are supervised closely by an experienced peer (Sinyai, Stafford, & Cpwr, 2013). This training encourages process of reflection or thinking with respect to actions taken by trainee, thereby strengthening ability of understanding cause and effect relationships between events, developing strategies and making decisions in case of emergency situations (Burke et al., 2006). However, results of a study conducted by Laberge et al. (2014) showed that due to age or experience difference, skilled employees did not explain all the risks associated with job - related tasks to new employees assuming some of the hazards are obvious to understand. Also, the work-related tasks are combination of dynamic and iterative events and employees need to learn multiple methods and apply them according to task requirements. However, there is a possibility that a peer may make the new employee understand only one way of dealing with the hazard. For example: Fire drills may help employees understand how to exit a building from their own workstation in case of emergency. However, it may not provide a thorough understanding of different ways to evacuate the building in case of fire. This could cause difficulty for an employee in exiting the building in the following scenario: There is an electric fire at the workstation in the production area and employee is trained to exit from workstation safely. However, the employee is in the cafeteria instead of the workstation when the fire alarm went off.

2.1.4 Simulation based training

In last few decades, e-learning has become popular than use of presentations, hands - on demonstrations in organizations to help employees improve their skills. A virtual simulation provides an environment for practice, interaction and immediate application of knowledge by forming a mental model for newly learnt information (Cuevas, Fiore, Bowers, & Salas, 2004). Simulation - based safety training allows dynamic decision making which gives learners better understanding of applying knowledge to the real-world situation. This not only provides real time feedback on a specific choice of the learner but also modifies environment as per the choices made by the learner. Employees interacting with objects in a simulation develop ability to interpret variety of relations, develop a habit of awareness and even think about surroundings before acting in real world situations (Myers & Francis, 2011). Virtual reality provides combination of immersion and interaction in an environment, which mimics the real world. Immersion provides experience to multiple senses such as touch, sound and sight whereas interactivity helps users to become part of 3D environment by providing them capability of performing actions such as moving, running and picking things up just as they would do in real environment (Hudock, 1994). Virtual - environment based education not only complements traditional classroom based teaching approach and supports information exchange (Ku & Mahabaleshwarkar, 2011) but also bridges gap between learning about a subject and learning by doing. Virtual reality utilizes computer, software and hardware to generate a 3D simulated environment which can be real or imaginary and it has capability to engage a user by creating a sense of being present in that environment (Sacks, Perlman, & Barak, 2013). It helps to overcome language barriers by providing experience based learning. Also, simulation based training allows to log the performance data of trainees which can be used to provide real time and summative feedback (Arai & Handayani, 2013). Simulation based training minimizes risks as trainees can be safely exposed to virtual fire or explosion scenario. Features of virtual environments range from tracking position and orientation of user and update virtual scene to match user's movements to allow user to control some of the objects to certain degree (Bailenson et al., 2008). To summarize, advantages and disadvantages of different safety training methods are as shown in table 2-1 below (adopted from (Bhide & Rabelo, 2015)):

Table 2-1 Summary of advantages and disadvantages of safety training methods

Type of Safety Training	**Advantages**	**Disadvantages**
Information - based training	Low cost	Less engaging, less emphasis on learning, unidirectional
Computer instruction - based training	Portable, low cost	Less engaging, less effective, unidirectional
Training with hands-on activities	Effective, engaging, interactive	Safety risk, high cost
Simulation - based training	Moderate cost, low risk, effective, engaging, interactive, experiential learning	Long development time

2.2 Simulations in health and safety training

Literature acknowledges importance of experiential learning and examples show that virtual reality based simulation training is proven to be more effective for training personnel on safety. Virtual simulation based training development has been identified as an effective tool for teaching skills in various industries such as construction, healthcare, machining and defense (Albert, Hallowell, Kleiner, Chen, & Golparvar-Fard, 2014; Chan, 2012; Dutton, 2013; Hu, Sun, & Dai, 2014; Waxberg, Goodell, Avgerinos, Schwaitzberg, & Cao, 2004). In order to understand effectiveness of implementing virtual reality based safety training in construction industry, Sacks et al. (2013) studied 66 subjects where half of the subjects received traditional lecture based training and remaining subjects were trained using 3D immersive virtual reality power wall. Safety knowledge of the participants was tested prior to the training, immediately afterward and one month later. Virtual reality based training was found to be more effective not only to maintain engagement of participants, but also in long term recall when participants were involved in cast-in-situ concrete works. Healthcare is another example of an industry where virtual simulations are widely used. Healthcare industry finds use of simulation based training useful in technical and procedural domains such as surgery, obstetrics and cardiology as well as in high risk critical care and emergency medicine (Nagle, McHale, Alexander, & French, 2009).

2.3 Live, virtual and constructive simulations

Live, Virtual and Constructive (LVC) simulations are three distinct classes of simulations from military point of view (Cane, McCarthy, & Halawi, 2010). In live simulation, real people are operating real systems. For example, shooting bullets at a cardboard target for training. In virtual simulation, real people operate simulated systems. Virtual flight simulator is an example of virtual simulation. In constructive simulation simulated people are operating simulated systems. Human behavior is modeled in this type of simulation. Example of constructive simulation is a war game (Hodson & Hill, 2014). Following table adopted from Kim et al. (2014) shows characteristics of LVC simulations.

Table 2-2 LVC simulation characteristics

Characteristics	Live	Virtual	Constructive
Participants	Real people operating real systems	Real people operating simulated systems	Simulated people operating simulated systems
Environment	Field exercise	Virtual environment	Computer generated environment
Interaction	Human- in- the- loop	Human- in- the- loop	-
Example	Multiple Integrated Laser Engagement System (MILES)	Virtual flight simulator	War game

2.4 Need for 3D virtual evacuation safety training

Evacuation of buildings during a state of emergency is an important aspect of safety training. Emergencies are not only situations of fire, smoke or chemical spills but also they include natural calamities such as earthquakes, hurricanes and floods. Posting written instruction on walls such as floor plans, doors marked with EXIT sign, “Do not use the elevator during emergency” notice and evacuation drills at workplaces are examples of traditional approaches of providing safety knowledge (Chittaro & Ranon, 2009). This information tends to be delivered in conventional formats such as the simple displays as well as pamphlets, emails, and newsletters that are sent to employees. However, visibility may become poor due to smoke or chemicals during real time emergency situations and following written instructions becomes difficult. Also, people can grasp limited details of surroundings due to stress that is induced during emergency situations (Leach, 2004). Emergency evacuation drill can be thought of as a training effort that focuses on a specific scenario. Though the importance of fire drills is undeniable, they are expensive and they may not present all aspects of an emergency or hazards to people. Also, fire drills may not make employees aware of various exit routes and possible strategies for evacuation based on different locations of fire (Chittaro & Ranon, 2009). So, a training that can make people visualize their usual environment and the situations they may face during emergencies could help them understand the course of action they should take to mitigate the risk in such emergency. A recent study has shown that people can learn about the place better by interacting with virtual model of complex, multi-level building (Münzer & Zadeh, 2016).

Krasuski et al. (2014) performed a Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis of use of virtual reality in fire evacuation training, see table 2-2. Some of the important weaknesses of virtual reality approach that are mentioned in this study are- 1) lack of validation and confirmation about how learnings from simulated world can be applied in real world, 2) ergonomic aspects, and 3) technical limitations inducing simulation sickness. This SWOT analysis provides insight on how virtual simulations are being used as a tool for fire evacuation training and what are the aspects that are still not addressed effectively.

Table 2-3 SWOT analysis of virtual simulations in evacuation safety training

Strengths	**Weaknesses**
• Replication • Safety of participants • Real time feedback • Precise measurement • Internal & External validity • Low costs • Easier participant recruitment • Possibility of psychophysiological measurements	• Need for validation/ confirmation • Technology Induced side effects such as simulator sickness • Individual differences in ease of interaction with VE • Technical limitations • Non-intuitive interaction methods
Opportunities	**Threats**
• Intuitive and natural navigation • Graphical developments • Multi-modal simulation and feedback • Usability for researchers • Exchange of 3D-scenes	• Failure to show ecological validity • Ethical challenges • Side-effects due to interaction with other medical conditions • Misleading expectations • Technical faults

2.5 Features of 3D Virtual Simulation Training

Virtual simulation based training should provide at least five features in order to be effective, namely- social, research, problem solving, experiential learning and transfer (Oblinger, 2006).

Social features are important as they develop a sense of community or competition during training. Research is the feature that allows a trainee to find new pieces of information and learn about their surrounding environment. By combining existing knowledge and new pieces of information, trainee performs various actions in simulated world. This aspect of learning is termed as problem solving. Experiential learning is the feature that allows trainee to learn from experience and multiple senses that are involved in simulation based training. Transfer of training can be defined as how effectively and continuously person can apply skills learnt during training in real life situation.

2.5.1 Social behavior

Social setting is one of the aspects identified as a gap in existing simulation - based training for emergency evacuation (Cha, Han, Lee, & Choi, 2012; Silva, Almeida, Rossetti, & Coelho, 2013). Silva et al. (2013) reported that after conducting a pilot study involving 20 healthcare professionals, they realized the need for developing multi-player game version that can help to understand social aspects and interactions involved when crowds are evacuating under emotional distress. Another virtual reality - based research was conducted by Sacks, Perlman, and Barak (2013) where groups of 10-12 participants were exposed to VR training but only few of the participants had a controller to navigate environment and interact with the scenario while others were observers. This study found that as the number of group members increases, engagement in training decreases due to limited interactivity. Also, providing first-hand control of environment to all the participants improves effectiveness of training. Multi-player approach can allow to further understand group behavior in emergency situations and how person’s individual and social behavior plays role in determining his/her safety. For example, how person behaves against pressure of time taken to evacuate the building and specific actions to be taken before evacuating the building such as helping a colleague or making a 911 call (Chittaro & Ranon, 2009).

2.5.2 Research

When a trainee is introduced to virtual world, he or she needs to understand rules and information along with her existing knowledge base to interact and maneuver in the virtual environment to successfully complete tasks. Participants need to explore and learn about the virtual environment

(Khanal, 2014). Capability of interaction provided in 3D simulations makes it possible for users to easily grasp the information. Also, he or she can be provided with cues or hints to understand concepts of interest.

2.5.3 **Problem solving**

Trainees are provided with scenarios in virtual world that they may or may not have faced in real life and they have to not only understand different aspects of that scenario but also have to find a way to solve the problem or take correct action. Problem solving develops an attitude in a person to find a solution in case of difficult situation (Oblinger, 2006).

2.5.4 **Transfer of training**

Understanding the connection between training and real world situations is the key to the transfer of training. The conditions of transfer of training are described as -1) generalization of knowledge and skills obtained from training to real situation (Baldwin & Ford, 1988), and 2) maintaining those skills over time on the job (Ford & Weissbein, 1997). Questionnaires are a commonly used subjective measures of transfer that is provided before and after training to evaluate learning effectiveness. Questionnaires can help understand retention of concepts, but it is difficult to measure how a trainee's actions in real situation will be affected due to training. Objective measures of evaluating transfer of training are used in flight simulators where a trainee is trained in the flight simulator for number of sessions and then is asked to operate an actual airplane with experienced pilot who assesses trainee's performance to determine transfer of training (Tian, Liu, Yin, Luo, & Wu, 2015). However, considering nature of risks involved in emergency situations, it is difficult to test knowledge or behavior of trainees in a real time scenario. Chittaro and Ranon (2009) identified transfer of training as a future requirement from their Simulation Based Training

(SBT) study developed for fire safety. Garrett and McMahon (2013) employed three methods of indirect measurement of transfer of training;

1) Inverse transfer of training method (how experts perform in simulator, without practice)

2) Assessment fidelity (physical similarity between simulator and real world environment)

3) Operator opinion (participant's perceived training value of simulator)

To evaluate transfer of knowledge testing in real world was not possible as this research involved training mining personnel on emergency evacuation in mine. Triangulation of these three indirect measures indicated that participants were able to use their existing knowledge of real world mine in simulator. But, novice needed more instructional support on simulator.

2.5.5 <u>Experiential learning</u>

Experiential learning happens in simulation based training as trainees receive feedback for every action performed in virtual environment in terms of score or what action needs to be taken next. Hence, when trainee performs an action, he/ she receives feedback and learns from it. Feedback is an important aspect offered in SBT that enhances experiential learning processes, provides motivation, helps the trainee learn from mistakes and reduces uncertainty about performance (Davis, 2005). Feedback can be delayed or immediate; where immediate feedback is provided depending on trainee's actions in an environment which results in temporary interruption of task. On the other hand, delayed feedback is either provided after every task/scenario (known as formative feedback) or after completing entire training session (also called summative feedback) (Billings, 2012; Khanal, 2014). A 3D simulation tool was developed to help construction workers improve hazard recognition skills via risk free experiential learning and feedback method (Albert, Hallowell, Kleiner, Chen, & Golparvar-Fard, 2014). A worker's avatar was expected to identify hazards and energy sources dispersed throughout a 3D environment. When a user identified any hazard stimuli, an interface form appeared on the screen which allowed the user to provide input on identifying the hazard source. Depending on the input, user received feedback from the system. Also, score (feedback) was displayed on computer screen along with information on successful and unsuccessful hazard identifications upon the completion of the game which can be considered as delayed summative feedback.

2.6 Training Assessment

Training evaluation helps in understanding factors in the training that make it appropriate for audience while training effectiveness focuses on how trainees learning is affected due to training exercise.

2.6.1 Training evaluation

Training evaluation can be described as a continual and systematic process of assessing the value or potential value of a training program or exercise, i.e. extent to which training meets the intended goals. Results of training evaluation are utilized to alter, continue or eliminate various components of the training such as design, delivery and results (US_Office_of_Personnel_Management, n.d.). Training evaluation measures training's success or failure in terms of design, content, learning and organizational payoff. Evaluation focuses on learning outcomes and is concerned with learning and on-job performance.

2.6.2 Training effectiveness

The terms training evaluation and training effectiveness are used interchangeably. Training effectiveness concerns with the variables that are likely to affect the training outcomes at the different stages of training (before, during, and after). Training effectiveness is concerned with measuring why individuals learnt or did not learn. Evaluation answers what occurred because of training and effectiveness answers why these results happened (Kaye, 2004).

2.6.3 <u>Methods for assessment of training</u>

2.6.3.1 Knowledge test

A knowledge test is commonly administered for training evaluation where participants are asked to take this knowledge test before and after training. Difference between test scores is utilized to understand learning level of trainees. Also, a knowledge test can be provided before training, after training and after certain duration later to check short term effectiveness, long term effectiveness and recall of the knowledge (Sacks, Perlman, & Barak, 2013).

2.6.3.2 Data log

Simulation based training allows to record participant's performance that can be analyzed later to understand effectiveness at various stages. Silva, Almeida, Rossetti, and Coelho (2013) developed a simulation based platform and recorded participants' behavior in a log data file of simulator.

2.6.3.3 Interviews / Questionnaires

Interviews are conducted with participants to understand user experience about features of a simulator that help or hinder learning experience (Silva et al., 2013). Views of participants are utilized to improve training on features such as fidelity and user interactivity.

Also, questionnaires mostly based on Likert scales are administered to participants after experiencing virtual simulation to understand feeling of simulation sickness and presence (Slater et al., 2006). Presence is termed as a subjective experience of being present in one environment while actually being present in another (Zahorik & Jenison, 1998). For example, a person present in virtual building of a hospital feels it similar to that of a real hospital building. Physical law inconsistency between visual, vestibular and peculiar information provided by virtual world that implied movement results in simulation sickness (Tanaka & Takagi, 2004), which is also measured using questionnaires.

In a research consisting of dental students and faculty, a new haptic simulator's ability as a tool in self-practice and teaching was assessed (Ben Gal, Weiss, Gafni, & Ziv, 2011). Subjects were asked to fill in questionnaires post training. Analysis of questionnaires helped to understand that all the subjects found use of simulator useful in learning and teaching process and students rating were high about convenience of using simulator for training. It was also found that tactile sensation of simulator was needed to be attuned to match real time sensation.

2.6.3.4 Physiological measures

Flow (state of extreme involvement in activity that makes nothing else matter), presence (psychological sense of being present in a virtual environment) and cognitive absorption (state of deep involvement with software) are three factors that describe engaging experience for computer games (Agarwal & Karahanna, 2000; Csikszentmihalyi & Csikszentmihalyi, 1992; Jennett et al., 2008; Slater, Usoh, & Steed, 1994). User engagement and user experience are different concepts; however, they are intertwined. User engagement is a purposeful choice that a user makes from available options depending on quality of experience.

User engagement in virtual simulation is a complex phenomenon and there are mainly two methods used to measure user engagement: 1) self-reporting, and 2) physiological measures (Milleville-Pennel & Charron, 2015). Self-reporting involves use of questionnaires, interviews, and surveys. Participant anonymity, capability of reaching large samples, flexibility of setting, and mode of administration are some advantages of self-reporting (Lalmas, O'Brien, & Yom-Tov, 2014). Self-reporting measures such as questionnaires or interviews answer the degree to which a participant actually felt engaged depending on user's interpretation or recollection of training (Kelly, 2009). Method or instrument bias can also affect validity of self- reporting (Burton-Jones, 2009). Also, questioning participants while they are exposed to training can affect their experience and presence in training (McMahan, Parberry, & Parsons, 2015).

Therefore, use of physiological responses such as change in galvanic skin resistance (GSR), variability of heart rate (measured using electrocardiogram (ECG)) or brain activity (measured using electroencephalogram (EEG)) are employed as supplementary tools (Kramer, 1990). Physiological signals are continuously available, which allows to study responses of participant to environmental stimuli without interruption (Lianekhammy, 2014). Physiological measures are objective indices where a participant is subjected to measurement without conscious awareness (McMahan et al., 2015). Electroencephalogram (EEG) has been used to determine engagement , attention level of trainees and also to measure cognitive workload (Berka et al., 2007) while GSR and ECG has been used as a tool to measure presence in virtual environment (Slater et al., 2006).

2.6.3.5 Transfer of training

As mentioned before, training evaluation is concerned with learning and on-job performance. Transfer of training is one of the dimension of training evaluation that measures how skills learnt during training are reflected in job environment (Kaye, 2004). It is one of the challenging parameters to measure, however it is important because if the change in behavior does not occur because of training, then training success is under question. As mentioned in previous section there are four commonly used techniques to measure transfer: objective, subjective, forward transfer and backward or indirect transfer (Vincenzi, Wise, Mouloua, & Hancock, 2009).

2.7 Emergency evacuation studies from Literature

Evacuation simulators are being used to test safety conditions of building in case emergency occurs and all the occupants have to leave the building. Stairs, number of exits, width of exits and physical characteristics of occupants are the factors of concern for these simulators. Level of life safety provided in buildings is assessed by computer based simulators. Computational evacuation models do not take into consideration interaction between occupants, effects of fire on building structure and decision making process of individual. Some simulators are freely available to public such as EVACNET, Simulex, EXODUS; while some are commercial software like STEPS, EGRESS (Kuligowski, Peacock, & Hoskins, 2010).

Sherman, Penick, Su, Brown, and Harris (2007) developed a simulation for visualizing wildfire. This research elaborates hardware and software based framework utilized to primarily visualize wildfire in specific terrain. But, actual user interaction with the systems has not been tested through the study. Thus, training effectiveness using this effort has not been yet established.

According to a research published by Ren, Chen, and Luo (2008), smoke and flames as observed during real life fire can be simulated using numerical fire simulation. They developed a system to simulate emergency evacuation during fire with emphasis on visualization of particles, flames and smoke spreading. This research also does not provide outlook on how this system was utilized for training. The research considers need for providing distributed interactive capability for simultaneous users as a future need.

Rui, Bin, Fengru, and Yu (2012) developed a 3D environment for virtual fire training based on OpenSimulator and SecondLife that can be used to train fireman trainees. However, fire disaster scenarios and avatars are developed from perspective of training firefighters and not the residents of building. Considering difficulty in conducting evacuation drills in burning buildings, Rüppel and Schatz (2011) proposed using Building Information Modeling (BIM) in serious game to develop realistic scenarios.

Maritime safety and security on board ships is important as it depends on the ability of crew to respond to an emergency, communicate in teams and effectively perform crisis management. Christoph, Knud, and Michael (2013) describe how a simulation environment is implemented for safety and security training in merchant maritime field. Officers, crew and service personal were offered simulation training which incorporated emergency scenarios such as fire, flooding and bridge evacuation. Training results showed that simulation based training optimized emergency management training and improved team performance along with collaborative learning.

In case of fire safety training, visible factors such as smoke and flames along with invisible factors like heat and toxic gases are important to model in simulations to make it immersive (Cha et al., 2012). A simulation training was developed by focusing on firefighters and firefighting commanders along with public as potential users. A framework for a fire training simulator was developed using computational fluid dynamics (CFD) for calculating various visible and invisible factors. The longest tunnel in South Korea was simulated and a fire scenario was designed using air flow speed caused by jet fan facilities, size of the fire, training type, control method and training starting point. A motion tracking device and head mounted display (HMD) were used. Activities that user's avatar was expected to perform comprised of simple tasks such as identifying accident, finding fire hydrant, firefighting, finding and evacuating nearby victims. Results of this research showed that use of CFD data about toxic gases and heat had direct impact on responses and rescue activities followed by users and it further helped improve knowledge of inexperienced users.

Ren et al. (2008) developed a virtual reality based building environment that can be used to conduct fire evacuation drills in a virtual environment. Not only evacuees can be made familiar with the evacuation process but also architects can test evacuation performance of building using such virtual drill environment. Allowing several users to participate in virtual fire drill is considered as a future work.

Research proposed by Mingze and Smith (2014) highlights training of fire wardens who are one or two residents that have responsibility to support evacuation process of the big buildings. They will introduce non-player characters (NPC) to see the interaction between players and NPCs during evacuation training scenario.

Fire simulation training can help not only firefighter commanders, officers but also trainees and public to make quick decisions to respond to actual fire situation and improve safety. Fire drills are unsuitable in establishment such as hospital as drills not only affect normal functioning of the hospital but also incurs financial costs (Silva et al., 2013). Silva et. al developed a preliminary 3D fire evacuation simulation game. A sample of 20 healthcare professionals was selected to test the hypothesis of applying simulation based training as an aid to improve traditional fire drill. It was observed that subjects with prior training in fire prevention performed better in the simulation. The preliminary results demonstrated viability of simulation approach, however further research and development was found to be required to improve scenarios, playability and adding multi-player capability in the game.

In another research, for personal fire safety, a 3D simulation game was developed from first person view where 3 floors of a university building each consisting of 100 rooms were designed. Game was organized in different levels such that each level had a specific fire emergency scenario with increasing level of difficulty. User was evaluated using time taken to evacuate the building and specific actions to be completed before evacuating the building such as helping a colleague or making a 911 call. This game helped not only on acquiring navigation knowledge of building but also facilitated learning and practicing various situations that may arise during fire emergency. This game also provided perspective on understanding various actions to be taken and procedures to be followed during emergency situations. Preliminary study with 7 participants identified limitation with general purpose 3D game engine (NeoAxis game engine), lack of availability of feature that allows player to personalize their character and realistic simulation of phenomenon such as fire or smoke (Chittaro & Ranon, 2009).

Smith and Ericson (2009) trained children on virtual simulator for reinforcing video based fire safety training. Cave Automatic Virtual Environment (CAVE) and 6DOF (Degrees of Freedom) wand were utilized to provide VR training. Children were provided with a pre- quiz and post-quiz to test their learning. Qualitative results showed that there were no conclusive short term learning gains.

2.8 Research Gap

Part of this subsection has been published in Bhide, S., & Rabelo, L. (2015). Framework for emergency evacuation safety training using 3D virtual simulation. *GE-International Journal of Engineering Research, 3*(7), 36-52.

Literature review depicted that there are several case studies on emergency evacuation using virtual simulation that have scenarios such as aircraft evacuation (Sharma & Otunba, 2012) , wildfire (Sherman et al., 2007), mining evacuation (Garrett & McMahon, 2013) and substation evacuation (Sharma, Jerripothula, Mackey, & Soumare, 2014). However, the focus of this research is on the emergency situations that are faced by residents of complex structures or buildings. Therefore, efforts were directed towards finding literature on evacuation simulation training for buildings. Also, there are different target audience for whom evacuation safety training is conducted, namely –1) firefighters, crew members and officers, 2) residents of the building, and 3) building architects and engineers. Table 2-3 shows studies from literature classified according to audience.

Table 2-4 Evacuation training studies from literature

Firefighters/ officers centered SBT	Residents/ personal fire safety SBT
Xu, Lu, Guan, Chen, and Ren (2014)	Smith & Ericson (2009)
Cha et al.(2012)	Chittaro & Ranon (2009)
Rui, Bin, Fengru, and Yu (2012)	Silva et. al (2013)
Christoph, Knud, and Michael (2013)	Ren (2008)
Rüppel & Schatz (2011)	Mingze and Smith (2014)
Wang, Lin, and Hou (2015)	
Wener et al. (2015)	

Most of the studies have focused on development of 3D model that replicates real world and effort has been made to make it realistic by enhancing visualization of phenomenon such as smoke, flames of fire that are observed in real world emergency. Silva et al. (2013) introduced fire alarm sound in the study to improve the ecological validity. However, few studies have utilized floor map of the real world building (Chittaro & Ranon, 2009; Xu, Lu, Guan, Chen, & Ren, 2014) and some studies identified development of building model based on floor map/ CAD drawing as a future work (Ribeiro, Almeida, Rossetti, Coelho, & Coelho, 2013).

Effectiveness of the virtual training, i.e. retention of concepts learnt from training or knowledge gain has been identified as a future work in most of the studies (Chittaro & Ranon, 2009; Xi & Smith, 2014). Pre-quiz and post-quiz was utilized as an instrument by Smith and Ericson (2009) to understand short – term learning gains. However, the results of the analysis of pre-and post-quiz showed that short- term learning was not impacted in positive or negative way due to training.

Literature corroborates that physiological measures such as GSR, ECG, EEG can overcome or at least complement use of questionnaires to understand performance related parameters such as presence and workload. EEG has been reported to accurately reflect subtle shifts in not only workload but also in alertness, engagement and attention (Berka et al., 2007). Studies shown in table below have not suggested use of physiological measurement or providing simulation sickness questionnaire to users.

Injecting intelligent agents for providing guidance has been identified by Smith and Ericson (2009). Need for adding computer controlled agents, NPCs or multiple players been identified to provide distraction, delay and social interaction. Ribeiro et al. (2013) have used computer controlled agents for clogging the passages and delaying player in finding exit during emergency.

Validation or confirmation about how learnings from simulated scenarios will affect behavior of participants in real world i.e. transfer of training is mentioned as one of the important weakness of virtual reality based training by Krasuski et al. (2014). It was found in literature review that very few studies validated virtual simulation based training for transfer of training and one study identified validating transfer, engagement and effectiveness as future need (Chittaro & Ranon, 2009).

Hence, based on these observations, a gap was identified as a need to address various factors such as transfer, effectiveness and evaluation of training along with virtual environment development, content, user perspective and visualization in emergency evacuation through a case study with larger number of participants. Figure 2-3 summarizes literature review and gap analysis.

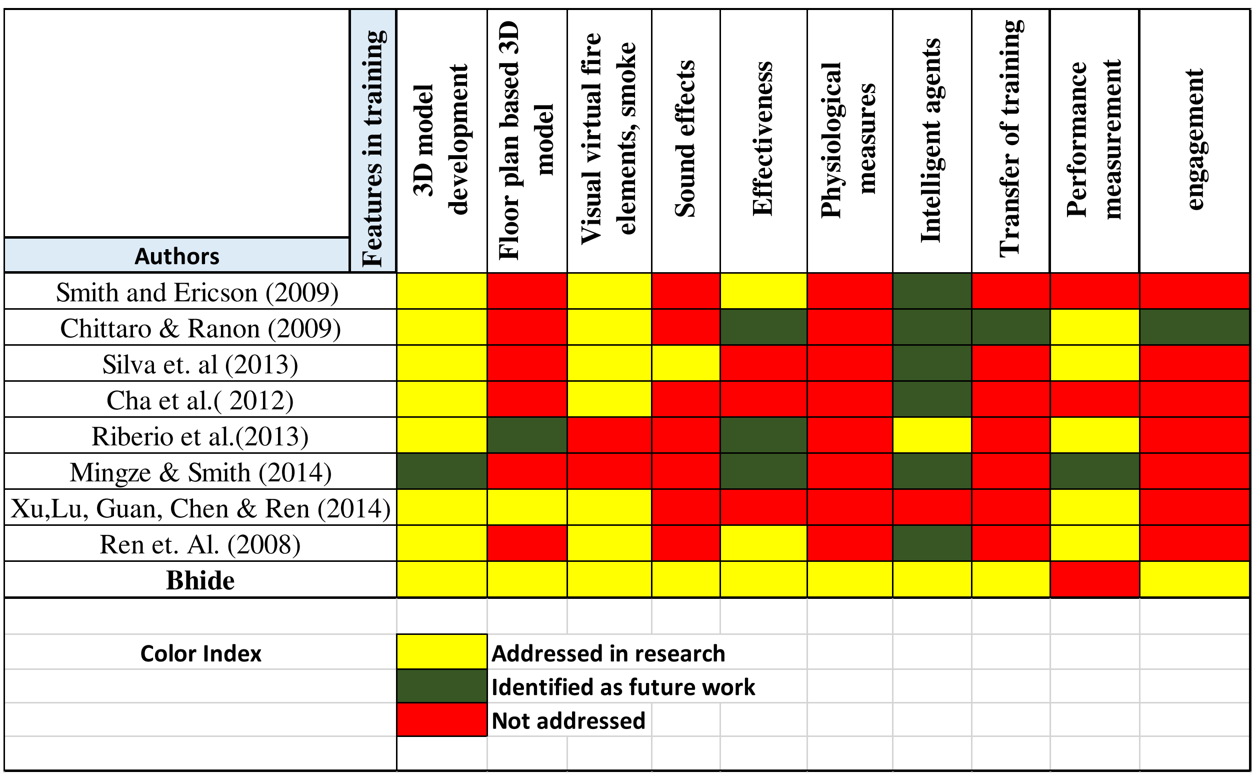


Figure 2-2 Gap analysis

CHAPTER 3 RESEARCH METHODS

3.1 Experiment 1 methodology

In experiment 1 participants were randomly assigned to 2 groups, first group underwent computer instruction based training while other group was provided with 3D virtual training. This experiment investigated fitness of 3D virtual fire safety training through simulation sickness and fidelity questionnaires. Also, experiment 1 sought to explore knowledge gain and subjective engagement experienced by participants in the 3D virtual world and computer instruction based fire safety training. A detailed methodology is explained as follows

3.1.1 Research participants

Potential participants were recruited with the help of professors who teach classes in engineering II building, College of Engineering and Computer Science. Fire safety and emergency evacuation training for this study was developed in 3D virtual model of Engineering II building. Hence, participant's familiarity with real building was an important factor in providing perspective on fidelity of the developed virtual environment. Potential participants were provided information about volunteering in the study during Spring and Summer 2016 classes. Participants were randomly assigned to part I or part II of the research study.

Participants mainly consisted of healthy male and female students from graduate and undergraduate classes. These students belonged to different engineering departments such as industrial engineering, mechanical & aerospace engineering, computer science, electrical engineering and civil engineering. This allowed to gather a random sample representing general population of students who usually spend time in the engineering building.

3.1.2 **<u>Procedure</u>**

3.1.2.1 Slide based training

In the beginning, participants of study were informed about purpose of the study. It was explained to them that their participation in the fire safety and emergency evacuation research was completely voluntary. It would not affect their coursework-in either positive or negative manner. This research would not identify participants in the research and aggregate results will be reported. This is not the kind of study that could negatively affect a participant's employability, insurability, or reputation. Participants were told that if they wish to remove themselves from study at any point in time, their records will be removed by researcher. Consent forms were distributed and were discussed with participants. After answering questions of participants and receiving verbal consent, participants were asked to become part of the study. Participants were asked to provide their email address which was used to contact them for retention test after 3-4 weeks from the day of study participation. They were provided with a demographic questionnaire that asked questions about age, gender, class standing and some questions related with their familiarity with video games and fire safety training.

The study was conducted in two parts. In the first part of the study, purpose of study was explained to participants. After receiving their consent to participate in training trainees typed an Office Mix link in desktop computers and underwent emergency evacuation training. Trainees were given instructions about how to navigate in Office Mix as soon as they went on the website of Office Mix. First, they were provided with categorical questions and a pre-test on fire safety. Interactions and response time of participants was saved. Then, they were provided with informative slides on emergency evacuation and fire safety. Appropriate images and effects were added in the slides. In the end, a post-test and questions about engagement experienced in training were administered. Trainees underwent following steps (figure 3-1) to complete the training.

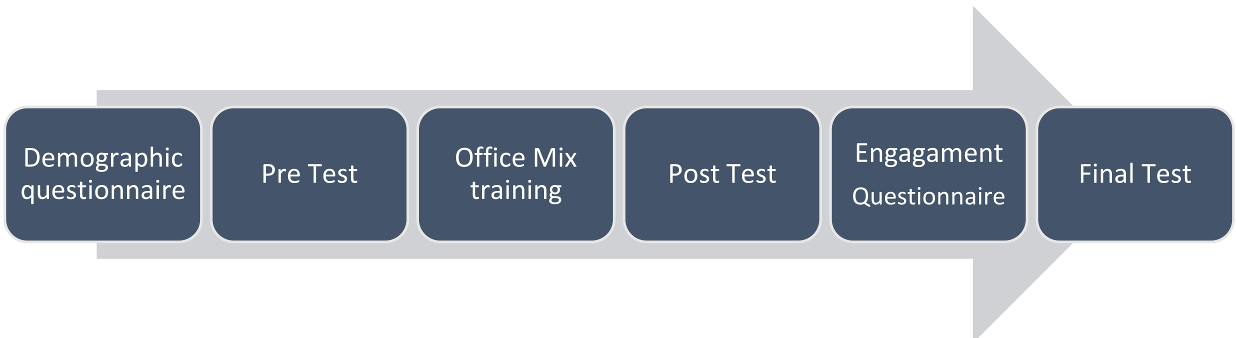


Figure 3-1 Procedure for slide based conventional fire safety training

After 3 to 4 weeks from training, participants were contacted again and were asked to take the similar knowledge test as of pre-or post knowledge test. This was the second part of the training study. Participants were provided with consent form similar to the consent form provided before participating in first part of the training.

3.1.2.2 3D virtual simulation based training

participants of study were informed about purpose of the study; participation was completely voluntary and whether to take part in the study was up to them. It would not affect their coursework, employability, or reputation. This research would not identify participants in the research and aggregate results will be reported. Participants were told that if they wish to remove themselves from study at any point in time, they just need to inform researcher and their records will be removed from research database. Participants were explained about a minor risk of simulation sickness that they might experience during their exposure to virtual safety training. Also, they were informed that these risks were no greater than the sickness risks participants experience if they were to play a video games such as second life or some games on play station. Consent forms were distributed and were discussed with participants. There was no time limit for completing study. Participants could take breaks as and when they needed and in case they experienced any of the symptoms mentioned, they were asked to report to researcher immediately.

After receiving verbal consent, they participated in virtual simulation study. Participants were asked to provide their email address which was used to contact them for retention test after 3-4 weeks from the day of study participation. They were provided with a demographic questionnaire that asked questions about age, gender, class standing and some questions related with their familiarity with video games and fire safety training.

In first part of the study, the purpose of the study was described to participants. Then they were provided with categorical questions and a pre-test. An introduction on how to navigate in virtual simulation was provided. Then a virtual simulation based emergency evacuation training was provided where participant could control an avatar on computer screen using a computer keyboard and a mouse. Interactions and response time of participants was saved. After the training, a post-test, few questions about engagement, simulation sickness and fidelity questionnaires were administered to participants. Figure 3-2 depicts the study procedure.

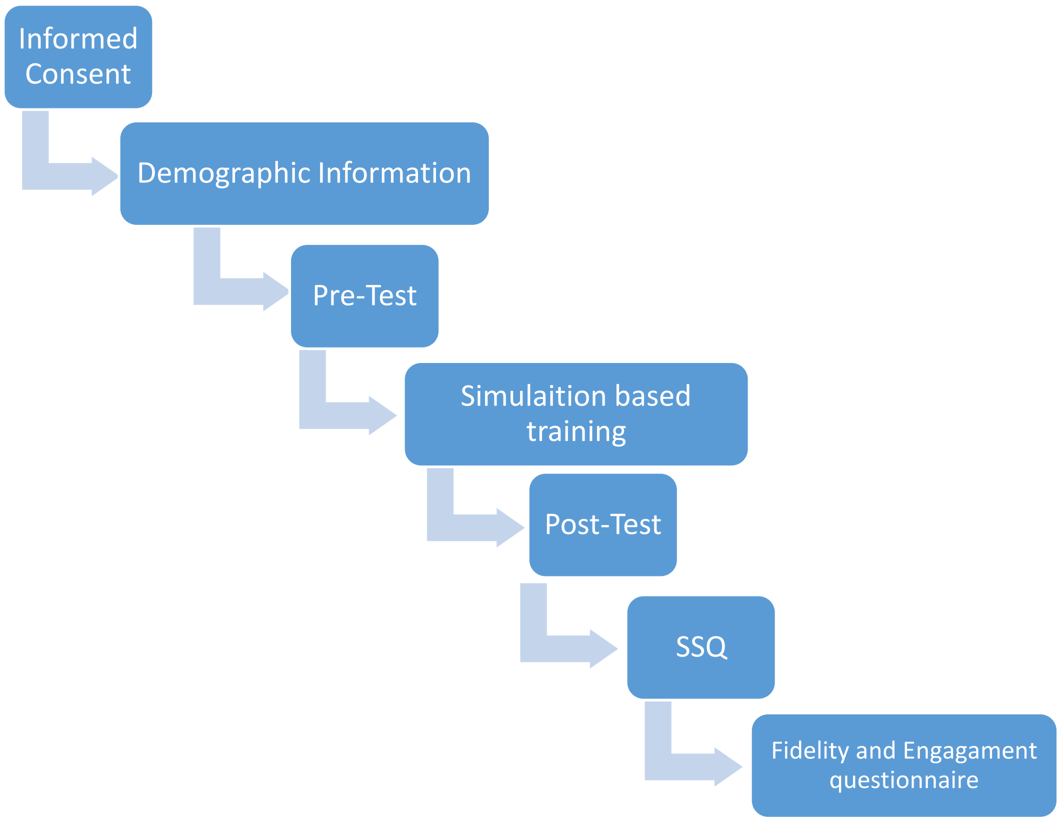


Figure 3-2 Procedure for 3D virtual fire safety and emergency evacuation training

After 3 to 4 weeks from training, participants were contacted again and were asked to take a knowledge test.

3.1.3 Research design

Experiment 1 utilized experimental research design. Knowledge test and engagement experience data was collected, analyzed and compared between two population groups. This study also studies variables such as age, gender, time spent on training, familiarity with fire safety training and virtual games. Simulation sickness and fidelity of simulation based training was studied through analysis of data obtained in this experiment.

3.2 Experiment 2 methodology

In experiment 2, relationship between attention/ engagement felt in 3D virtual training and computer information based training was explored using objective measurement. Participants were randomly divided into 2 groups and were provided with different trainings. Electroencephalogram (EEG) was recorded for the duration of the training. Participants also completed pre-training and post training questionnaires and knowledge test.

3.2.1 Research participants

Experiment 2 had 40 healthy male and female participants. Participants were requested not to consume coffee before participating in this experiment. These 40 participants were divided into 2 groups randomly. The first group was provided with 3D virtual fire safety training whereas second group underwent slide based training. Participants consisted of male and female students from graduate and undergraduate classes from different departments of college of engineering and computer science. Also, few faculty and EHS experts participated in experiment 2.

3.2.2 Procedure

Research was explained to participants and they were provided with consent form. Participants were explained that this study will not affect their insurability or employability and participation will not affect their coursework in any manner. They were shown EMOTIV EEG headset that was going to be used to record electrical signals generated by brain while participant was exposed to fire safety training. Also, they were told to immediately report to researcher in case they feel uncomfortable, itchiness of scalp or any uneasiness during experiment. After receiving verbal consent of participants, they were provided with pre knowledge test and demographic questionnaire. Then the participant was asked to take a seat in front of computer and were asked to sit as comfortably as possible to operate computer using keyboard and mouse. Then EEG instrument was placed on scalp of participant and it was made sure that data was recording properly on EEG testbench software provided by EMOTIV. Then participant was instructed to open eyes for 2 minutes and close eyes for 2 minutes. This signal was recorded as a baseline.

All participants took a pre-test and a demographic questionnaire. Then, participants from slide based training group viewed slides on fire safety and emergency evacuation training and participants from 3D virtual training interacted with simulated virtual fire safety scenarios. For all participants, EEG signal was recorded while they underwent fire safety training. After participants completed training, the EEG headset was removed and all participants were provided with post knowledge test and engagement questionnaire. 3D virtual study group also received SSQ and fidelity questionnaires in addition to post knowledge and engagement questionnaires.

Procedure for slide based training with EEG signal recording is depicted in figure 3-3. Figure 3-4 shows study procedure for 3D virtual safety training with EEG recording.

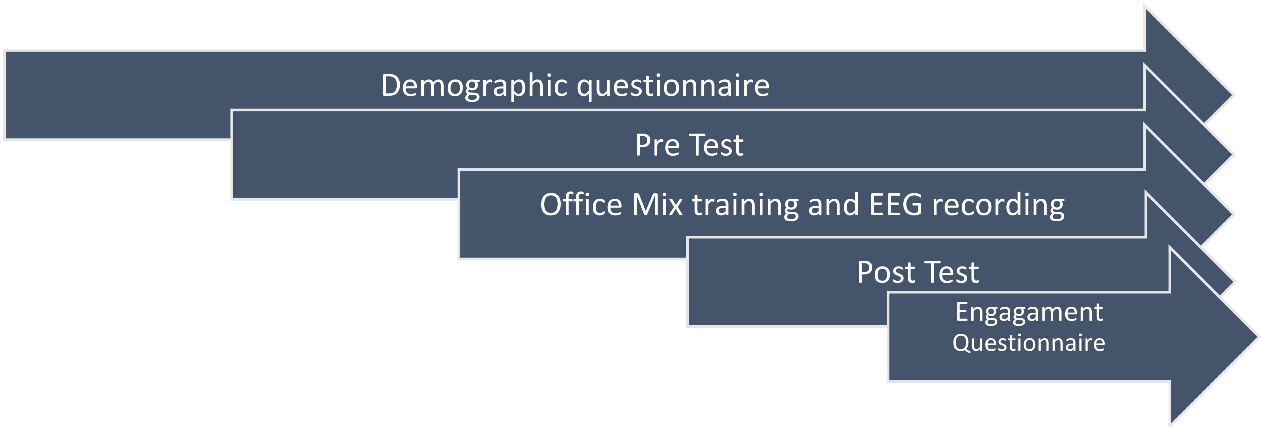


Figure 3-3 Procedure for EEG recording for slide based training

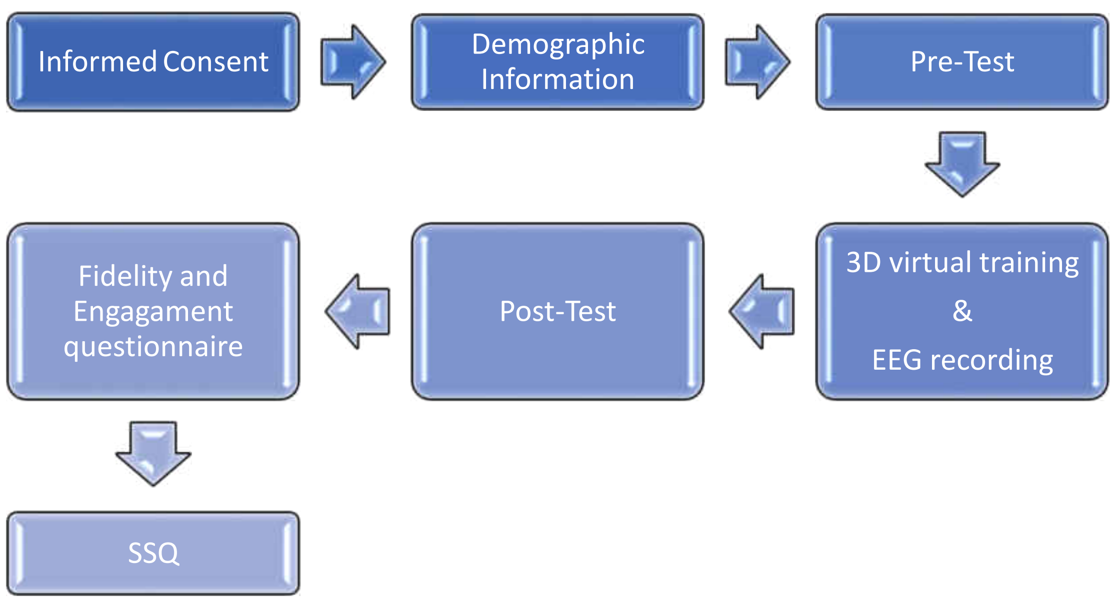


Figure 3-4 Procedure for EEG recording for 3D virtual training

After a month, trainees were contacted and asked to take final knowledge test.

3.2.3 <u>Research design</u>

Experiment 2 utilized experimental research design. Effort was made to focus on independent variables virtual safety training and conventional safety training. EEG data obtained for participants was processed to obtain power spectrum values which are then statistically compared to see effect of two training treatments on engagement.

3.3 Statistical analysis

Engagement, simulation sickness, fidelity and knowledge questionnaire obtained from all the participants were analyzed statistically. To test the hypothesis about knowledge tests, within group (slide based training, 3D virtual training), paired t-test is used while to test hypothesis between virtual training and slide based training group, independent two sample t- test is used at degree of certainty, α, in the 95^{th} percentile.

Following are the hypotheses for 3D virtual training

1. Difference between mean of pre and post knowledge test will be significant
2. Difference between mean of pre and final knowledge test will be significant
3. There will be minimal simulation sickness experienced in virtual simulation by trainees.
4. 3D Virtual engineering building will be perceived very similar to that of real engineering building (high fidelity)

Hypotheses for conventional safety training

1. Difference between mean of pre and post knowledge test will be significant
2. Difference between mean of pre and final knowledge test will be significant

Hypotheses for comparison between two trainings

1. Knowledge gained in 3D virtual training will be equal or better than that of slide based training
2. Engagement experienced in 3D virtual training will be better than slide based training
3. Time spent in 3D virtual training will be more than slide based training

Likert scale (5 point) was utilized in fidelity and engagement questionnaire. As this is an ordinal scale, non-parametric test was used for hypothesis test.

Alpha, beta, gamma and theta bands were plotted for each subject's denoised EEG signal power spectrum. Following are the hypotheses that were tested for experiment 2:

1. Sustained attention of participants in 3D virtual training will be more than slide based training.

3.4 Training assessment questionnaire

Training evaluation is a continual and systematic process of assessing the value or potential value of a training program. Results of training evaluation provide inputs in order to alter, continue or eliminate components of the training such as design or delivery. Assessment instruments used for this research are based on studies from literature (Sacks et al., 2013; Smith & Ericson, 2009)

Evaluation of factors like fidelity and simulator sickness could help in providing insights on performance of virtual environment.

3.4.1 Simulation sickness questionnaire (SSQ)

Simulator sickness (SS) is considered as a type of motion sickness that is induced due to exposure to virtual environment (VE). Symptoms include disorientation, nausea, dizziness, sweating, drowsiness, eyestrain, headache, etc. It depends on type of VE, participants and tasks carried out in VE (Milleville-Pennel & Charron, 2015). It is important to study if any simulator sickness symptoms are induced in participants as it can lead to distraction, decrease in motivation, negative transfer of training, risk to health of participants, and most importantly compromising effectiveness of simulation based training exercise, limiting its usage (McCauley, 1984). It is observed that flight simulators, driving simulators and use of head mounted display (HMD) or CAVE generally induce SS in participants (Drexler, 2006). However, it is reported that experience of simulation on desktop or personal computers can also induce SS. Hence, it will be considered important to measure SS for this study. The most widely used method for assessing the symptoms induced due to exposure to virtual environment is the Simulator Sickness Questionnaire (SSQ)(Kennedy, Lane, Berbaum, & Lilienthal, 1993). There are 16 items on SSQ that form 3 sub-scales: 1) Nausea, 2) Oculomotor symptoms (such as headache, eyestrain and blurred vision), and 3) Disorientation. Participants have to rate these items on the scale of 0 to 3. Figure 3-5 shows questionnaire that was administered to participants after they underwent SBT of fire safety and the computation for total SSQ score

	0 (None)	1(Slight)	2(Moderate)	3(Severe)
General discomfort				
Fatigue				
Headache				
Eye Strain				
Difficulty focusing				
Increased Salivation				
Sweating				
Nausea				
Difficulty in concentrating				
Fullness of head				
Blurred vision				
Dizziness (eyes open)				
Dizziness (eyes closed)				
Vertigo				
Stomach awareness				
Burping				

Figure 3-5 Simulation sickness questionnaire

SSQ is based on three components- nausea, oculomotor and disorientation. Total SSQ score is obtained by adding these 3 components. As shown in figure 3-6, weights are applied to each of the 16 simulation sickness symptoms reported by participant for each column, and then summed down the columns. The total SSQ score is obtained by adding the scale scores across the three columns and multiplying by 3.74 (Kennedy et al., 1993).

Table 3-1 Scale for classification of SSQ (Kennedy et al., 2003)

SSQ SCORE	Categorization
0	No Symptoms
< 5	Negligible symptoms
5-10	Minimal symptoms
10-15	Significant Symptoms
15-20	Symptoms are a concern
>20	A problem simulator

	Nausea	Oculomotor	Disorientation
General discomfort	1	1	0
Fatigue	0	1	0
Headache	0	1	0
Eye Strain	0	1	0
Difficulty focusing	0	1	1
Increased Salivation	1	0	0
Sweating	1	0	0
Nausea	1	0	1
Difficulty in concentrating	1	1	0
Fullness of head	0	0	1
Blurred vision	0	1	1
Dizziness (eyes open)	0	0	1
Dizziness (eyes closed)	0	0	1
Vertigo	0	0	1
Stomach awareness	1	0	0
Burping	1	0	0

Figure 3-6 Weights applied to symptoms

Once the score is calculated, it can be used to reflect severity of symptoms in participants and can also index troublesomeness of simulator. Scale shown in table 3-1 is used to understand how virtual simulation on fire safety was perceived by participants.

3.4.2 Fidelity questionnaire

Fidelity is similarity between virtual world and real world. It is important to understand the degree to which trainee feels virtual world is the reflection of real world objects (Sweetser & Wyeth, 2005). Likert scale based questionnaire is used to measure fidelity of 3D virtual fire safety training

(Appendix C). In fire safety and emergency evacuation training, some of the important factors from fidelity perspective are- 1) similarity between real Engineering II building and 3D virtual world building 2) Fire equipment such as fire extinguishers, exit signs, exit ways 3) texture of walls, windows, ceiling and so on, and 4) introduction providing information on objectives and navigation.

3.4.3 Training effectiveness

Training effectiveness is concerned with measuring what individual learnt or did not learn after conducting training program. Training effectiveness can be measured by utilizing knowledge test during various stages such as before training, after training, after certain duration of training. Instead of providing paper based questionnaire, knowledge test can be accommodated in virtual training and trainee's responses can be saved into database. This data of knowledge test before, after and after certain duration can be compared to see how much knowledge is gained and retained by trainee (Sacks et al., 2013; Smith & Ericson, 2009).

In 1956, Benjamin Bloom collaborated with Max Englehart, Edward Furst, Walter Hill, and David Krathwohl to publish a framework for categorizing educational goals known as *Taxonomy of Educational Objectives or Bloom's Taxonomy*. This framework consists of 6 major categories: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation (Bloom, 1956). Each of these categories can be explained in relation with designed fire safety training further as illustrated in table 3-2

Table 3-2 Bloom's taxonomy utilized in fire safety training knowledge test

Category	Explanation	Fire Safety training
Knowledge	Remember or recollect information learnt in training slides	Few questions were included to see recollection of information from training
Comprehension	Demonstrate understanding of facts and ideas from training by organizing, comparing, translating, interpreting	Questions based on facts mentioned in training slides were asked to trainees
Application	Use acquired knowledge, facts, ideas learnt in training to apply or solve problem in different setting	4 questions provided scenario of real life situations and trainees were expected to apply information learnt in slides to solve problem.
Analysis	Break down provided information into parts based on causes or relationship. Make inference and find evidence to support generalization.	A case and 4 questions on it were presented to trainees for analysis.
Synthesis	Combine pieces of information in a different pattern or way or propose alternative solution.	
Evaluation	Critically examine information and make judgment based on it	

3.4.4 Trainee engagement

Engagement or attention of trainee in training can be measured either with the help of questionnaires or by utilizing physiological measure. Engagement questionnaire for this study is based on questionnaires used in literature (Fu, Su, & Yu, 2009; Sacks et al., 2013; Sweetser & Wyeth, 2005). Measuring engagement of trainee in simulation based evacuation safety training as compared to conventional methods is an important assessment factor. There are many physiological measures such as GSR, pupillometry, EEG and ECG. EEG allows to record and analyze brain wave pattern generated during thought process using a computer interface (McMahan et al., 2015). EEG has been acknowledged to accurately reflect subtle shifts in mental alertness, engagement and attention (Berka et al., 2007). Therefore, in experiment 1, engagement experienced by trainees is captured using questionnaire and in experiment 2, EEG is utilized to explore trainee's response during virtual simulation based training and conventional training method of fire safety.

EMOTIV EPOC instrument was used to record electrical signals generated by brain of participant undergoing fire safety training. An electroencephalogram (EEG) measures the electrical activity in the brain (brain waves) using electrodes (small metal discs or sensors) placed on the head in a completely non-invasive manner. This EEG headset device is light and fits perfectly to user's head shape and doesn't interfere with user movement. The lightweight headset applies easily, is conductive gel free and can be utilized easily at home, lab, or operational setting. This headset is widely used by many students and scholars. Also it is reported that this EEG headset has comparable quality as of medical devices (Yaomanee, Pan-ngum, & Ayuthaya, 2012).

3.5 Experimental validity and control

3.5.1 Topics covered in training

Fire safety and emergency evacuation training was provided in two ways, in the form of slide based training and 3D virtual training. Based on literature and expert opinion contents of training were developed and evaluated by two experts. It was crucial that same underlying topics were explained to trainees in both types of training. Also, there was no time limit on completing training and trainees were told that they could revisit training contents any number of times.

3.5.2 Selection bias

Selection of participants for study and their assignment to type of training could introduce bias in the collected data. Before approaching classes, some date and time slots were randomly assigned to slide based training and 3D virtual training. Participants of this study were from existing undergraduate and graduate classes and students were asked to choose a date and time slot of their convenience for participating in the study. So, it was made sure that participants were not aware of the type of training they were assigned to. At no point participants were removed from results. However, in case of electroencephalogram recording, certain data resulting from actions such as eye blinks or muscle movements that introduces noise in neural signals was removed. Data of subject was not recorded or was deleted from records, if the subject felt uncomfortable and requested to stop recording or if there was an instrument failure.

3.5.3 Confounding effects

Various factors such as historic and character traits, learning abilities, determination and past experiences could play a role in understanding concepts and retaining them. Such factors are related with human behavior and are difficult to quantify. These individualized effects are mitigated by using enough large sample and randomizing which training participant will undergo. Participants of both trainings completed the training exercise on desktop computers in the industrial engineering lab and 3 to 5 participants were in training in any one session. Hence, same environment was maintained for both training treatments.

3.5.4 Researcher and evaluation bias

There is a chance of researcher bias clouding experiment design and evaluation process. To avoid that, at every phase in research study expert validation was applied. From feedback of experts, modifications were made. For example, a concept was duplicated on two slides, which was removed when an expert pointed it out. Also, textures of windows and carpet were changed in virtual building to match perfectly to real building as per expert's opinion. Training contents and instruments were based on existing literature and expert opinion. Standardized instructions were developed and presented to participants of both training groups by researcher to avoid introduction of any bias. Also, once data was collected, all information identifying subjects was masked to conduct blind evaluation of data.

In case of EEG data analysis, neural signals of participants were normalized before statistical analysis to remove the individual's effects on neural activity.

CHAPTER 4 DEVELOPMENT OF FIRE SAFETY AND EMERGENCY EVACUATION TRAINING

This chapter explains development of contents, slide based and 3D virtual simulation based fire safety and emergency evacuation training. Development components are shown in figure 4-1.

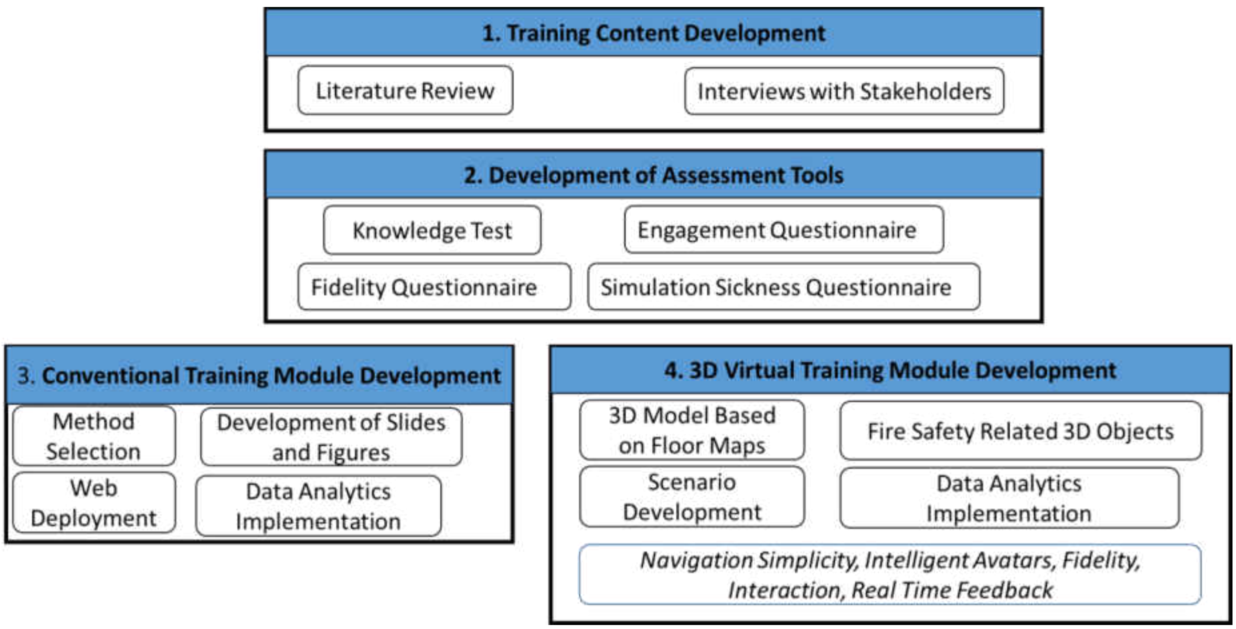


Figure 4-1 Framework of fire safety and emergency evacuation training development

4.1 Fire safety and emergency evacuation training content

This section explains steps followed in developing safety training for university students. First step was development of training materials. Fire safety and emergency evacuation training content was created based on interviews of experts and existing literature on the subject.

Most commonly used training techniques for evacuation safety are: floor plans, "do not use elevator in case of emergency" sign posted next to elevator, use of EXIT signs and fire drills. Apart from existing training techniques, literature describes use of interviews with experts or review of documents and reports published by agencies (Sacks et al., 2013) such as Occupational Safety and Health Administration (OSHA) or Bureau of Labor Statistics (BLS) to analyze most hazardous situations pertinent to the industry under study which can be used as a baseline for virtual simulation. For example, fabrication labs in the university utilize hydrogen gas in some processes. Leakage of hydrogen could result in a serious explosion. Understanding real work environment from point of view of participants is also important. Hence, interviewing some employees or safety personnel from the building could be helpful to get insights. Contents developed using this process are used to develop a slide based training that is employed popularly in companies. Also, the same contents will be used to develop scenarios in the simulation based training. For example, a slide will explain about which exits one should take in case of emergency and how to avoid use of elevator. While, simulation based training will present a scenario where trainee will be asked to find nearest exit when he/she sees smoke in his/her office.

4.1.1 Lean Startup methodology

This research utilized the method of lean startup to get inputs for development of safety training. The lean startup methodology advocates development of products/ services based on validated learning, i.e. learning requirements from customers and asking for their feedback quickly and often to improve system under development.

Students, professors, professionals and industry experts were interviewed to understand safety training provided in their organization from their perspective. Lean startup interview process was adopted to get unbiased opinions on the fire safety training system. Interview process helped to understand frequency of fire safety training, audience of training and what level of knowledge is expected to be acquired by trainee.

45 individuals of varied ages, races and genders were interviewed in period of 5 weeks to understand various aspects of safety training ranging from who should receive training, the best way for providing training and challenges faced by businesses. 20 professionals working in various industries such as manufacturing, airline, animation, software, learning solution, energy, aerospace and theme parks were interviewed. Four of the professionals had a work experience in industry as well as a faculty in the university. 15 interviewees are categorized as Environmental Health and Safety (EHS) experts. Designation of these EHS experts ranges from safety consultant to safety manager. 4 lab assistants who work in university labs were interviewed along with 6 students to understand safety training's utility and its impact on student life.

It was identified that research assistants received fire safety training course using an online training tool and students who live in dorms undergo evacuation drill once a semester if they are present in the dorm at the time of drill. Staff/ faculty and research lab assistant have to complete online module once a year and they also receive hands-on training once a year. Afterwards they need to complete refresher course. Environmental Health and Safety (EHS) experts belonged to various organizations such as University of Central Florida, Siemens, Jabil Circuit, Disney World and Kennedy Space Center. EHS experts and professionals not only explained what should be the objectives of safety training but also suggested scenarios for developing training and knowledge test.

Table 4-1 shows learnings from interviews of potential users/ influencers of the safety training

Table 4-1 Learnings from stakeholders of fire safety and emergency evacuation training

Stakeholders	Top Learnings
Students	1. All students don't receive fire safety and emergency evacuation training. 2. Students living on dorms participate once a semester in fire drill if they are present in the dorm at the time of drill. 3. Research assistants in research lab receive mandatory fire safety training.
Professionals	1. Completing same fire safety training every year in computer instructions form or lecture form is tedious. 2. Repetitive and verbose nature of training makes it boring. 3. Overtraining can make people neglect/ forget important safety related information specific to their job. 4. Transfer of training is the biggest training challenge! 5. Flexible timings for training are critical for busy professionals, merely making training mandatory doesn't ensure that employees pay more attention to it.
EHS experts	1. Careless behavior is a major cause behind accidents, which can be changed with better retention of safety training. 2. Virtual simulations can aid in training but it cannot replace existing training 3. Information should be provided to humans in such a manner that they can form a mental model which could help in decision making. 4. People are being trained with slides for long time. Introducing 3D virtual training could be interesting but challenging in terms of conveying concepts. 5. 3D virtual training can be used for assessment of knowledge gained by trainees instead of providing training.

4.1.2 Literature on fire safety training

As audience of this safety training is university students, existing fire safety training from various universities was studied. Power point slides were developed based on the existing literature and training and was provided to 2 experts for feedback. Information on fire safety and emergency evacuation was studied from websites of Research and Training Center on Full Participation in Independent Living at the University of Kansas, Arkansas state university, University of Central Florida, University of Maryland Eastern Shore, and University of Texas. This information formed basis of fire safety slide based module.

After interviewing safety professionals and experts from different organizations and studying literature, following topics were identified essential to be covered on fire safety and emergency evacuation training:

- Recognize different types of fires and fire extinguishers
- Get familiar with emergency safety procedures
- Realize when to flee and fight in case of fire emergency
- Learn PASS (Pull, Aim, Squeeze and Sweep) method of using fire extinguisher
- Understand basic steps to be followed before, during and after emergency

It was identified that how much time participants spent on Power Point slides could be an important factor responsible for retention of concepts from training. In order to capture time spent by trainees on each slide, Office Mix was chosen as a tool to display slides and provide questionnaire to trainees. Office Mix a free add in tool of Microsoft that allows to create and share contents in the form of slides. Demographic questionnaire, pre -test, post-test, engagement and slides comprising of information on fire safety were included in Office Mix slides. Also, a knowledge test was provided a month later to check the long term retention of trainees(Wener et al., 2015).

4.2 Slide based training development

Information based or slide based safety training is popularly used in organizations where employees or students watch information in the form of slides with limited or full sound, images and/or video capabilities. This training is portable as trainee can watch information in any location and can learn at his/her pace. Considering this, slide based training was chosen as a conventional training mode for proposed fire safety training. Also, from interviews of industry experts and professionals it was evident that slide based training is used most popularly in organizations to train employees on health and safety. Even in universities, faculty, staff and research assistants are required to complete slides based training on safety.

4.2.1 Platform for slide based training

Office Mix is a free add-in tool for power point that allows to create and share slides along with questionnaire and polls. Also, Office Mix provides data analytics capabilities. It shows how much time was spent by each user on each slide and saves responses of trainees to the questionnaires. Office Mix allows to download data in the form of Excel sheet which can then be used with statistical analysis software. Slides developed for Office Mix had appropriate images and five to six bullet points per slide. At the start of the training there were few slides with a small introduction of how to navigate in Office Mix and what were goals of fire safety and emergency evacuation training. Then trainees were presented with a demographic questionnaire and pre-test followed by 32 slides on fire safety and emergency evacuation procedure. Then, participants took a post test and engagement questionnaire. Overall there were 81 slides in Office Mix including training and questionnaires.

4.2.2 <u>Slide based training evaluation</u>

Office Mix training was reviewed by two experts, one from industry and one from University of Central Florida. They filled a form that provided their feedback on the training content as shown in figure 4-2. Slides were edited to accommodate changes as per reviewer's feedback. For example, information on how to leave building in case of emergency was repeated on two slides, one of the slides was removed after this was pointed out by one of the reviewers.

Feedback

Please rate following statements in a scale of 1 (strongly disagree) to 5 (strongly agree)

	1	2	3	4	5
1. Objectives of training are sufficient for educating university students on emergency evacuation in case of fire.					X
2. The content covered in the slides is adequate to achieve the stated objectives.					X
3. Material is presented in a logical sequence.				X	
4. What would you recommend should be removed from the training?					
Response: Some points are written twice					
5. What would you recommend should be added in the training?					
Response: actual fire drill twice in a year					

Figure 4-2 Example of feedback obtained from one of the reviewers

4.3 3D Virtual fire safety and emergency evacuation training

There are multiple dimensions to the development of safety training that educate personnel on risks involved in surroundings and train on mitigating those risks. Three important dimensions are shown in figure 4-3 as: development of the virtual environment that is representation of the real world, learning and knowledge building experience gained by trainees, and evaluation &

effectiveness of training. Following section is published by Bhide and Rabelo (2015) in GE-International Journal of Engineering Research.

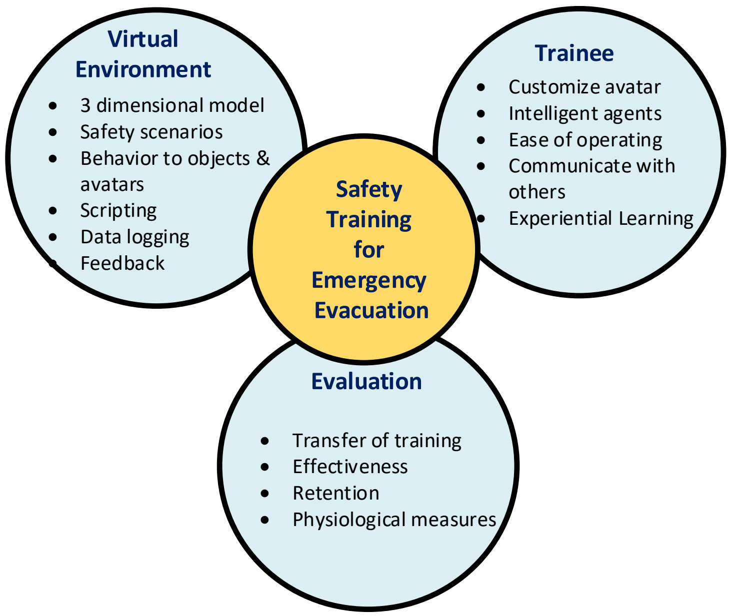


Figure 4-3 Dimensions in virtual fire safety and emergency evacuation training

- **3D virtual training development**

Developing a virtual environment consists of various subtasks-

- Developing 3 D model using proper tools that reflects real world.
- Developing scenarios based on contents pertinent to that industry. For example, conducting expert interviews or reviewing literature to understand important hazards in manufacturing industry and focus on them during development of simulation based training.

- Provide behavior to various objects in virtual world such as smoke particles and flow of water so that interaction of trainees with these objects will improve learning experience.
- Programming behaviors in non-player avatars that can interact with trainees.
- Providing database connection to save actions and answers of trainees that can be utilized for data analysis.
- Providing real time feedback based on response of participants to shape their decision making.

❖ **Trainee**

From trainee's perspective following are the aspects that could matter

- Simplicity of operating and navigating in virtual environment.
- Ability to customize avatar by choosing features such as appearance, clothes.
- Ability to communicate with others just as of a real life environment which is possible in case of multi-player approach or single player approach with non-player participants.
- Learning by doing, capability to interact and immerse in virtual environment where one learns by trial and error method or can practice skills easily.

❖ **Evaluation**

To improve training and performance of trainees, evaluation dimension can comprise of following

- Ability of participants to practice knowledge gained from training to real surroundings
- Effectiveness of training intervention as compared with other training methods
- Quality and duration of concepts learnt in training that can be retained by trainees

- Level of engagement, attention and subjective performance induced by simulation based training

This section explains how a 3D virtual model of a real building was developed in virtual world so that trainees can interact with it using an avatar. Figure 4-4 shows the steps in development of 3D virtual fire safety simulation and emergency evacuation training.

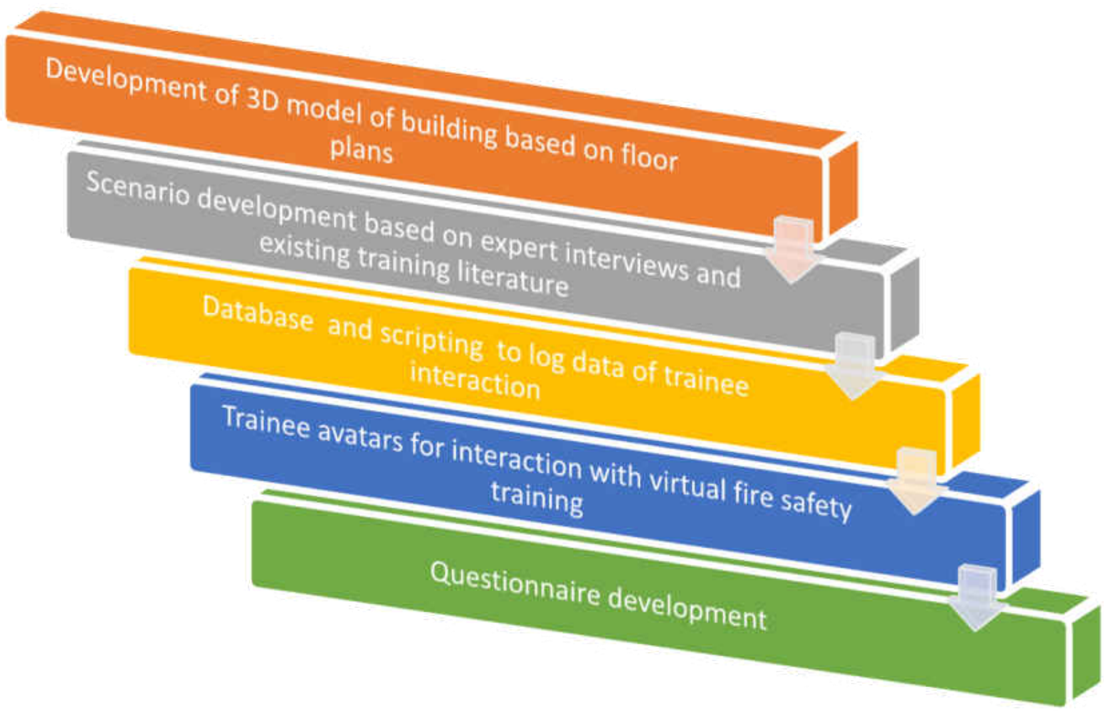


Figure 4-4 Steps of development of 3D virtual simulation

4.3.1 Platform for virtual environment: OpenSimulator

Choosing a modeling tool, graphics interface and software to base the system are factors that play crucial role in determining if the final developed simulation would meet its requirements.

Making the right choice of simulation software is very important as every simulation may not need advanced or unique features that are responsible for increasing costs to five to six digits. For example, simulation training that will be run on desktop computer may not need features of a flight simulator (McDowell, Darken, Sullivan, & Johnson, 2006). Literature review depicts that various software are used by researchers and developers in designing and building virtual simulation based training. After considering various factors and conclusions from numerous researches, it was decided to use OpenSimulator as a tool for developing virtual simulation.

The community outreach academic unit at Tulane University utilized OpenSimulator for delivering online instructions to students in year 2010. It was observed that student participation rate increased from 10% to 33% in online courses that offered virtual world activities. Also, students rated virtual world based learning higher than traditional online course learning activities and classroom based learning in terms of engagement, interactivity and understanding of the course content (Maxwell & McLennan, 2012).

In the University of La Sabana, a case study depicted that Second Life based virtual world can be a support tool in learning subject like electronics. Advantage was that participants were absorbed and more involved making learning process effective. But, it was also responsible for distractions as Second Life allowed students to access other worlds with different contents and social networking (Beltrán Sierra, Gutiérrez, & Garzón-Castro, 2012). Also, it was observed that Second Life platform had a tremendous potential to be used for virtual simulation training purpose, however it lacked component of confidentiality and data security. On the other hand, OpenSimulator, is an open source initiative with features such as persistent simulation, stable virtual environment and content portability along with secured communication and data sharing capabilities (Maxwell, 2013). 3D virtual world objects in OpenSimulator are interoperable and they can be provided with behaviors by using scripts. It allows researchers to upload their own content and create designs independent of designers, artists or modelers (Maxwell & McLennan, 2012).

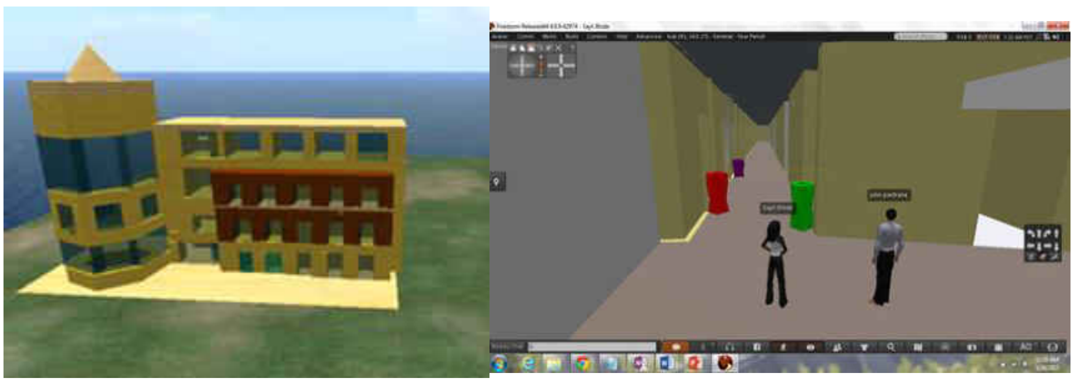


Figure 4-5 3D model and user interaction in OpenSimulator

It has capability of providing multiple players (Pinheiro et al., 2012) and a standard region in OpenSimulator allows 40 avatars to be present in virtual world at a time. Players can customize their avatar by choosing avatar's appearance like skin, hair and accessories like clothes and shoes. Also, OpenSimulator allows trainees to communicate with each other using voice calling, instant messaging and chat. Figure 4-5 shows example of basic 3D model development and user interaction in OpenSimulator (Bhide & Rabelo, 2015).

OpenSimulator is an open source platform which supports persistent simulation, stable virtual environment, content portability and has a programming interface (von Kapri, Ullrich, Brandherm,

& Prendinger, 2009). It allows to communicate with external systems without changing code of platform. OpenSimulator was selected for development of virtual fire safety simulation training considering advantages such as high performance, less distractions, low cost and ease of programming. OpenSimulator, utilizes Linden Scripting Language (LSL) which follows structure similar to widely used programming languages C and Java. LSL is a simple and powerful scripting language that is used to create interactive content and to control and manipulate objects in the simulated environment. Primitive objects are the basic building blocks in OpenSimulator that are used to develop 3D objects ranging from large structures to furniture and clothing. Primitive objects can be provided with behavior using scripts written in LSL. Participants will be able to see a 3D model of the environment on a computer screen and interact with it by simply using a keyboard and mouse through an avatar.

4.3.2 Virtual 3D model of engineering building

3D model of engineering building was developed using basic building blocks or primitives in Open Simulator. OpenSimulator also allows to import models developed in other 3D modeling software such as Sketchup or Maya.

Images of floor plans were imported in OpenSimulator and model of building was developed with reference of floor plan images using primitive objects (figure 4-6). There are 6400 primitives used in construction of this virtual building. Textures of wall colors, carpet, ceiling, floors, windows, stairs and doors in virtual building were chosen to be as close as of real engineering building. Figure 4-7 shows real and virtual engineering II building model.

Figure 4-6 3D virtual building development with real floor map

Figure 4-7 Real engineering building (Left) and virtual engineering building (Right)

Though the 3D model of entire engineering building is developed in OpenSimulator, fire safety training is mainly designed around 4th floor of the virtual building. If a person understands fire safety and emergency evacuation procedures for 4th floor, he/she would be trained for all the floors of engineering building as they have same locations of safety signs and emergency exits. Introduction area is modeled in the atrium of the virtual building. After undergoing introduction, trainees can choose to teleport to 4th floor for training or can take stairs or fly. Figure 4-8 shows interior of virtual Engineering II building consisting of four floors. Safety equipment such as fire extinguishers, fire alarms, pull stations and exit signs were modeled and located as of real world engineering building. Example of placement of fire alarms, fire extinguishers, exit signs are shown is figure 4-9.

Figure 4-8 Engineering II building floors

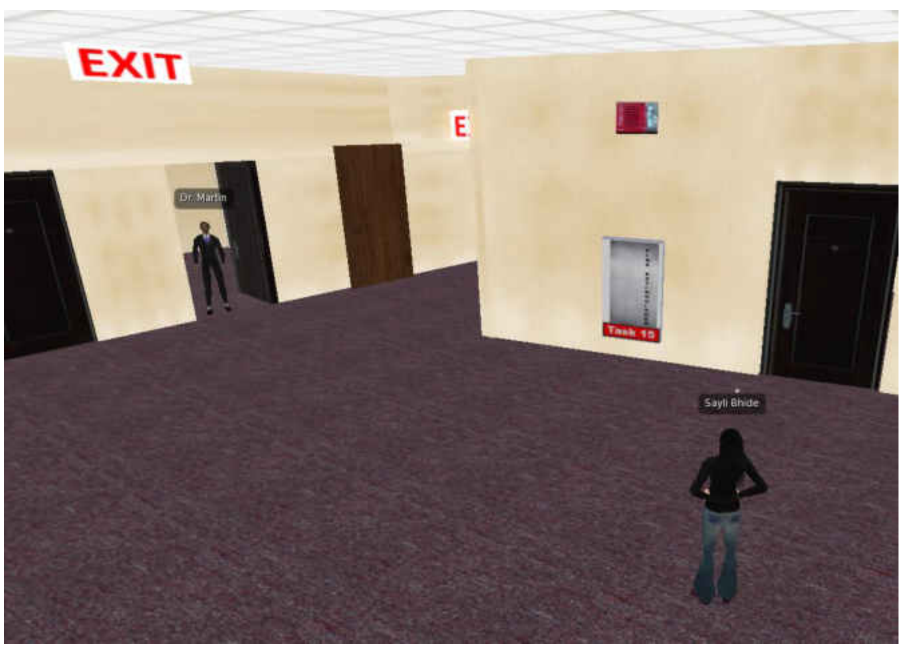


Figure 4-9 Placement of fire safety equipment

One of the tasks in the training briefed trainees that if they hear fire alarm, they should find nearest exit which would take them outside the building from 4th floor. As soon as avatar walked near a certain fire alarm pull station, a proximity sensor code would detect the avatar and would start alarm sound. Then, the sole task for trainee is to take avatar to nearest exit. Once, avatar reaches stairs for correct exit, they would see a sign indicating successful completion of training.

One of the advantages of virtual training is that it allowed to present fire safety content in various forms as shown in figure 4-10. There is a video explaining how to fight fire using fire extinguisher. Slides and posters are posted on virtual building walls to provide information on elements that are responsible for causing fires, fire extinguishers, types of fires, etc. 15 tasks were created in the training where trainee would see a question or task after clicking on a task number and was provided with appropriate response. Trainees could choose way of learning material per their preferred style.

Some of the tasks were designed to make trainees visualize and understand how they should react to real life scenarios such as scenario of fire coming out of the laboratory or fire in a waste basket (figure 4-11).

Figure 4-10 Example of multiple ways of presenting training content

Figure 4-11 Scenario of fire in a waste basket

4.3.3 Database and scripting

In virtual fire safety training, feedback is provided after every task. For example, while avatar is walking in the simulated environment, trainee would see smoke coming out of the closed door of the lab and avatar is asked about action that he or she would take in this case. A dialog box opens on the screen asking question along with options from which a correct answer needs to be selected (figure 4-12). Depending on the selected option, appropriate feedback is provided to trainee (figure 4-13).

Figure 4-12 Example of a question displayed by an object

Figure 4-13 Example of feedback received by trainee for her interaction

Developers can program most of the desired functionality using LSL. However, in the default state, the actions performed by participants in virtual environment are not available later for data analysis. To achieve persistent data storage functionality, MySQL database is used in this research. Response of trainee will be saved in a database which can be utilized for further analysis and providing feedback to the trainee.

PHP is a widely used open source general purpose scripting language. Virtual world based on OpenSimulator is running on one web server while MySQL database is working on another web server. Hence, there is a need of a mediating tool that can capture data from virtual world and save it to database. To serve the purpose of communicating between virtual environment and database, PHP scripting was used (figure 4-14). When trainees touched an object, they were displayed with a task and their response to the task was sent over internet and written in database table using PHP script.

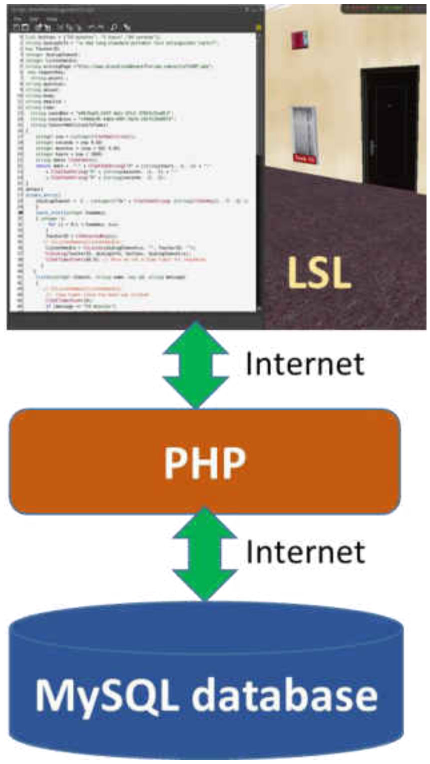


Figure 4-14 Database and OpenSim connection

Scripts are essential to provide behavior to objects in virtual world. There are various scripts in fire safety and emergency evacuation training that range from introduction area to non-player characters. Each task has a script that opens a dialog menu displaying a question when trainee avatar touches task object. Then as per choice of button pressed by avatar, same script displays response to avatar about the choice made. A script is written that instantiates a sound file corresponding to a right answer or a wrong answer.

There is a proximity sound response file encoded in every fire alarm. So, as soon as trainees touch task 15 and move in proximity of any fire alarm, they start sounding and trainees are asked to find the nearest exit.

In scenarios portraying fire that has started in waste basket or computer, a script is written that generates visualization of flames and runs a script that plays fire cracking sound. Script in task 1 explaining 3 elements of fire is based on Realfire by Renee (http://www.outworldz.com/cgi).

When a trainee attempted a task, time of task attempted was saved in database. By default, OpenSim server time is shown in Pacific Standard Time (PST). So, time of task attempted was converted to hour: min: sec format and appended with present date and sent to database. This script helped to acquire data about time spent by trainees on different tasks.

4.3.4 Scenario development

Scenarios in the virtual fire safety training are based on literature review and interviews of experts as explained in section 4.1. Hence, slide based and simulation based training both are based on same baseline.

4.3.4.1 Introduction area

Introduction area is developed in the atrium of the virtual Engineering II building, as shown in figure 4-15. At the start of the training, trainees enter virtual building atrium and see posters explaining navigation, objectives of virtual training and functions such as touch and teleport.

Figure 4-15 Snapshot of introduction area

4.3.4.2 Task 0

This task welcomes trainees to fire safety training and asks them to type their email address. These email addresses were utilized for contacting them for a completing a knowledge test after 3 to 4 weeks.

4.3.4.3 Task 1

This task is focused on making trainee aware about chemical reaction between oxygen, combustible material and source of energy results in fire. Tasks prompt trainee to touch each of the 3 boxes with fire element as shown in figure 4-16 and once they touch the box, they see a small description about that element. Also, once trainee touches an element, it sets itself on fire to symbolize its role in causing fire.

Figure 4-16 Snapshot of Task 1 in virtual engineering building

4.3.4.4 Task 2

In task 2, a scenario of smoke coming out of the closed door of the laboratory is faced by trainee. There is fire safety information posted on doors of the lab along with NFPA diamond. Then, trainee is asked whether he/she would choose to fight or flee in provided circumstances. Depending on their choice of action, they see response from task 2.

4.3.4.5 Task 3

In this task, a fire is coming out of the closed door and trainee is asked whether he/she would choose to fight or flee in this case.

4.3.4.6 Task 4

In this task, another scenario of commonly observed real life fire situation is developed. There is a fire in a waste basket and trainee is asked if he/she would fight or flee this fire. Tasks 3 and 4 are illustrated in figure 4-17.

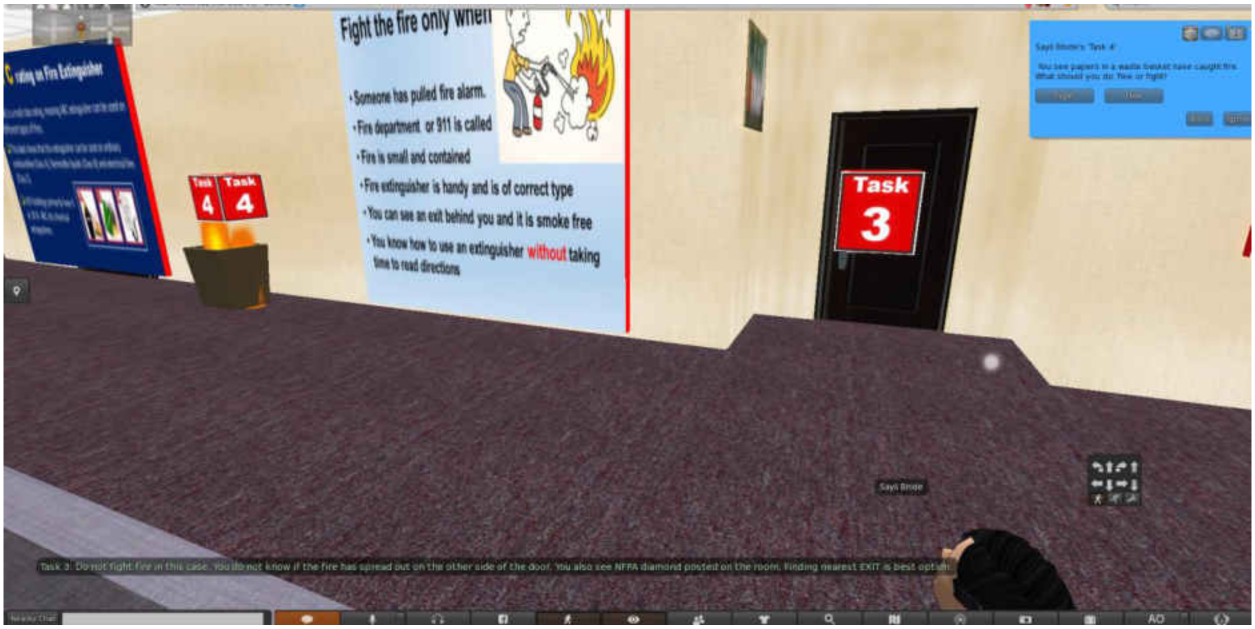


Figure 4-17 Tasks 3 and 4 based on fire safety scenarios

4.3.4.7 Task 5

A desktop computer is shown to have caught the fire and participants are asked which fire extinguisher would they choose to fight this fire.

4.3.4.8 Task 6 to Task 9

Task 6 to task 9 display questions related with Class A, B, C and D of fires. Depending on trainee responses, they are provided with information on which fire extinguishers to use against which class of fire.

4.3.4.9 Task 10 to Task 13

Task 10 to task 13 display questions specific to the university. For example, what type of fire extinguisher is usually found in UCF, how long does a standard fire extinguisher lasts, how many exit routes are there in engineering building, etc.

4.3.4.10 Task 14

In this task, trainee has to click on a button of the elevator and trainee is presented with a question that if she would take elevator in case of fire emergency as it is the fastest way to exit the building.

4.3.4.11 Task 15

In this last task, trainees would hear fire alarm and were asked to find nearest exit. One of the exits was closed so that they needed to find another exit (figure 4-18). This scenario was based on an expert opinion that residents of building should know at least two exits, in case one of the exits gets closed due to fire or smoke or emergency itself.

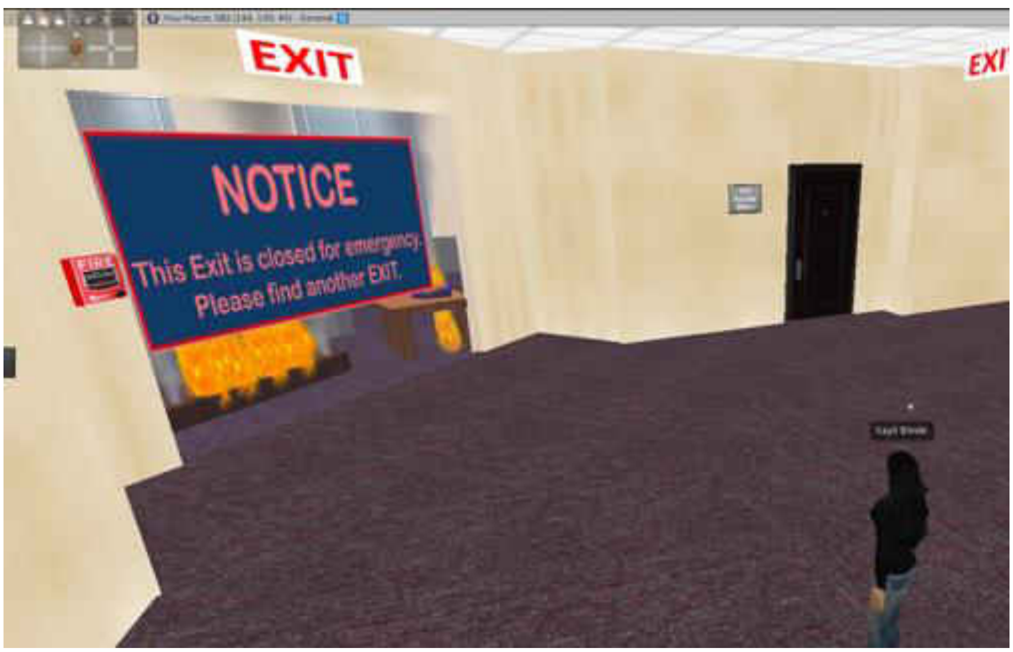


Figure 4-18 Example of closed emergency exit due to fire emergency

4.3.5 Avatar

Avatar of a trainee is a 3D representation of a person who can walk, run, touch and interact with objects in virtual world. 4 male and 4 female avatars were created prior to training for interacting in virtual world. Figure 4-19 shows example of trainee avatars. Trainees were randomly assigned avatars at the time of training. 3 to 4 trainees underwent training at the same time. Each trainee could interact with virtual environment on a desktop computer assigned to him/her using standard keyboard and mouse. Trainees wore headphones to listen to sound effects. Trainees were able to interact with each other. However, training activity was focused on individual training rather than team based training. Trainees could touch various objects in virtual 3D engineering building and learn information from it.

Figure 4-19 Example of male and female avatars of trainees in virtual world

4.3.6 Non-player characters

Non- player characters (NPC) are the avatars that are preprogrammed by developers for specific functions such as guiding trainee avatar or to provide directions in virtual world.

LSL is used for programming behavior in objects. For example, a computer is set on fire and smoke dispersion is established using scripting. Also, one can attach specific set of actions to few avatars who can interact with trainee. These avatars are controlled by developer rather than player; thus, they are known as non-player characters. This feature is explored to see social behavior aspect of the trainees.

Four NPC's were programmed in the 3D virtual fire safety and emergency evacuation training whose basic function was to guide trainees, remind them about tasks and help in navigation. For example, NPC Kelly directs participants to find second nearest exit way when they find out that one of the exits is closed due to emergency (figure 4-20).

Figure 4-20 Example of a NPC

4.3.7 Virtual training evaluation by experts

An expert on 3D virtual simulation development reviewed virtual engineering building developed in OpenSim and provided her feedback. She reviewed 3D modeling of safety related equipment, non-player character behavior, textures of various building components such as walls, carpet, stairs, etc. Based on the comments of the reviewer, textures of carpet, stair mat, wall color, size of the doors, movements of a NPC were modified. Also, previously training only contained introduction, 15 tasks and videos on fire safety. But, considering suggestion of expert reviewer, a board continuously displaying summary slides for training was added.

After modifying training as per suggestions of an expert in 3D virtual simulation, two of the EHS personnel from UCF were asked to participate in training as subjects. They underwent fire safety training in virtual engineering building as well as completed engagement, fidelity and simulation sickness questionnaire. As they were aware with the building and fire safety procedures, inverse transfer of training was observed. Inverse transfer of training method involves experts to perform tasks in simulation training without any practice. A positive result implies that the simulation training is appropriate for the purpose (Hale & Stanney, 2014). One personnel answered all the questions in training correctly while other answered only one question wrong. Both experienced no simulation sickness.

In response to the fidelity questionnaire, experts found that virtual engineering building and atrium were similar to real building structure. They agreed that fire safety equipment and fire elements resembled those in real life. One of the experts suggested that fire alarm sound can be made louder and lights in the fire alarms need to start flashing as soon as there is an emergency.

Response to engagement questionnaire shows that they strongly agreed that training presented new content in enjoyable form and they would like to undergo same training next year as shown in figure 4-21.

virtual training engagement (scale: 1- strongly disagree to 5- strongly agree)							
	new content	enjoyable experience	too much info	difficult to concentrate	retention	modified response	same training next yr
Expert 1	5	5	1	2	4	4	5
Expert 2	5	5	1	1	5	5	5

Figure 4-21 Expert opinion on virtual training engagement

CHAPTER 5 MEASUREMENT OF ELECTROENCEPHALOGRAM

A physiological measure called EEG, was employed in second part of experiments to understand attention of trainees in conventional fire safety training vs in 3D virtual fire safety training.

EEG makes it possible to measure voltage fluctuations that result from ionic current flows within neurons of the brain. EEG signals fall in the range of 1-35 Hz for most of the brain activity (Li, Zhao, Xu, Ma, & Rong, 2013; Prabhakara & Kulkarni, 2014). Some of the important frequency bands and their characteristics are described in table 5-1 (Surangsrirat & Intarapanich, 2015). Recorded EEG signals of participants were analyzed to understand changes in power in various frequency bands with respect to training treatment (slide based training and 3D virtual training).

Table 5-1 EEG frequency bands and characteristics

Band	Frequency Range (Hz)	Observed during following human activities
Delta	$0.5 \leq f < 4$	Adult sleep, some continuous attention tasks
Theta	$4 \leq f < 8$	Drowsiness/ idling in adults, response repression
Alpha	$8 \leq f < 13$	Normal rhythm in adults, relaxed and calm state of mind
Beta	$13 \leq f < 30$	Active thinking, focused, alert mental state
Gamma	$30 \leq f$	Cross modal sensory perception (audio and visual)

5.1 Instrument used for data collection

EMOTIV EPOC was used as an instrument to record electrical signals generated by brain of participants undergoing fire safety training. As shown in figure 5-2 (adopted from (Bhide et al., 2015), EPOC hardware which was employed to record neural signals of participants consists of a headset, 14 electrodes, hydrating saline solution, wireless connectivity dongle and charger for EMOTIV headset battery charging. The electrical activity in the brain (brain waves) was measured using electrodes (small metal discs or sensors) placed on the head in a completely non-invasive manner.

Figure 5-1 shows fourteen channels of EMOTIV as per 10-20 international system as: AF3, AF4, F3, F4, F7, F8, FC5, FC6, P7, P8, T7, T8, O1, and O2 with two additional reference electrodes. Sampling rate is 128 Hz and bandwidth is 0.5 to 64 Hz. Channel locations as per international 10-20 locations are shown below (McMahan et al., 2015).

This EEG headset is lightweight, fits smoothly over user's head and doesn’t interfere with user movement. The lightweight headset applies easily and can be utilized easily at home, lab, or operational setting. This headset is widely used by several researchers (Fok et al., 2011; Khushaba et al., 2012; Khushaba et al., 2013). Also it is reported that this EEG headset has comparable quality as of medical devices (Yaomanee et al., 2012).

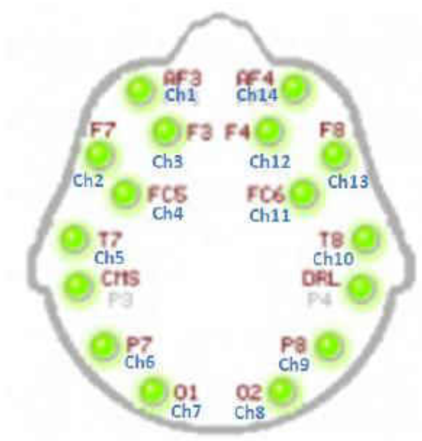


Figure 5-1 Emotive EPOC headset channels mapping

Figure 5-2 EMOTIV EPOC

5.2 Data collection

At first, the participant was asked to take a seat in front of a desktop computer. The felts of electrodes were hydrated and fitted to the EEG headset. Then EEG headset was placed on participant's head such that electrodes contacted participant's scalp. Figure 5-3 shows EMOTIV

EEG headset placed on the scalp of a participant undergoing virtual fire safety and emergency evacuation training.

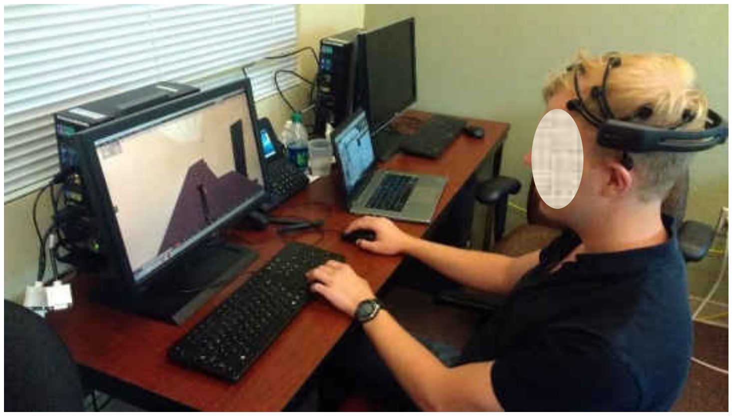


Figure 5-3 A participant with EPOC headset

Once the EEG headset is turned on, it sent signals to a laptop computer using wireless device. EMOTIV Testbench software was opened on researcher's laptop computer and the color of electrodes on contact quality panel was noted as shown in figure 5-4. The electrode placement was adjusted until all of them turned green. Color of electrodes in Testbench is an indication of quality of contact between electrode and scalp of participant. If the electrode color is red or black in Testbench, it indicates bad contact. Orange color shows acceptable contact and green is the best contact for capturing brain activity signals.

At the beginning of EEG recording, signal was recorded with participant's eyes open for a minute and half and eyes closed for a minute and half. Then the participant started the fire safety training exercise. Manual markers were sent in data recording when participants were going through the training tasks or when disturbances occurred.

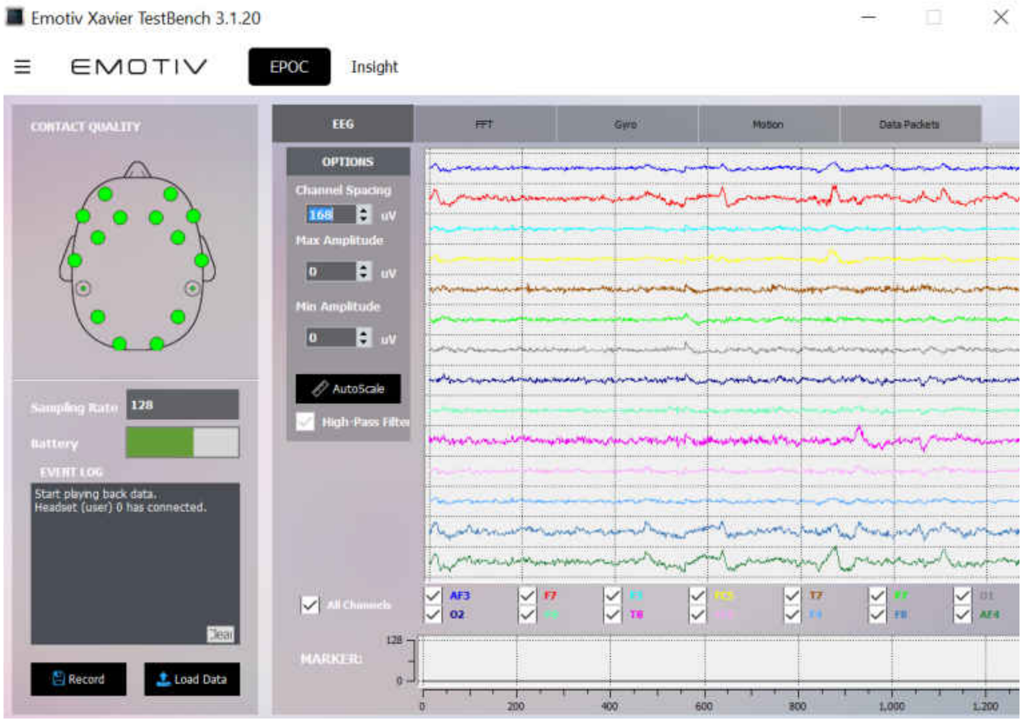


Figure 5-4 Data recording in EMOTIV Testbench software

5.3 Data Processing

For each subject, a .edf file was generated by EMOTIV. First this file was converted to .csv file and then unneeded columns of data such as counter, time in seconds, gyro information were removed. Columns corresponding to 14 channels and markers were retained in .csv file. Sampling frequency of EMOTIV is128 Hz. Hence, there were 128 rows recorded for each second spent by one participant on training.

EEG signal recorded by electrodes from scalp of a person is a combination of neural signal and artifacts. EEG artifact is a noise generated in EEG signal that contaminates the signal. Eye blinks, muscle movements, line noise, amplifier situation are some of the major sources of artifacts (Cohen, 2014). Artifacts recorded in EEG signal such as eye blink, muscle activity, etc. may have higher magnitude than neural signal. Therefore, it is necessary to remove the artifacts/noise from EEG before the data can be analyzed further. It is difficult to remove noise completely from EEG. Commonly applied methods of removal of artifacts are manual or semi-automatic selection of data to be rejected from entire signal. However, this method has subjective component and depends on the skill set of researcher. Removing noise manually poses a risk of removing some of the underlying neural signal. Methods of artifact removal that apply filtering are preferred by some researchers. Independent component analysis (ICA) is perceived as a powerful and robust method of artifact removal. ICA separates recorded raw EEG signal into statistically independent components and tries to remove components responsible for artifacts. However, ICA requires researcher to have experience and prior knowledge about nature of artifacts and removal of artifact can also reduce underlying neural signal.

This research utilizes wavelet enhanced independent component analysis (wICA) method of artifact removal. First MATLAB was used to remove line noise at 60 Hz by applying notch filter and a high pass filter was applied to remove low frequency noise at 0.5 Hz from recorded signal. Then entire data in .csv file was divided into 15 second intervals and wICA algorithm was applied to it for denoising (Castellanos & Makarov, 2006). Figure 5-5 and figure 5-6 show raw data and data after artifact removal obtained using EEGLAB toolbox in MATLAB (https://sccn.ucsd.edu/eeglab).

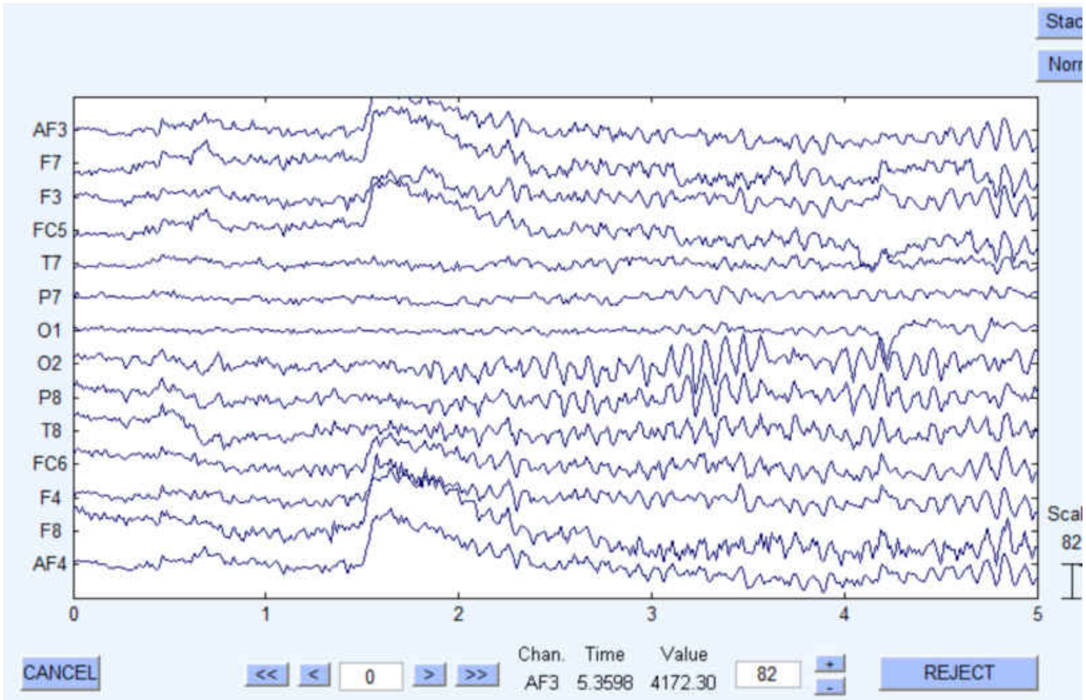


Figure 5-5 EEG raw data

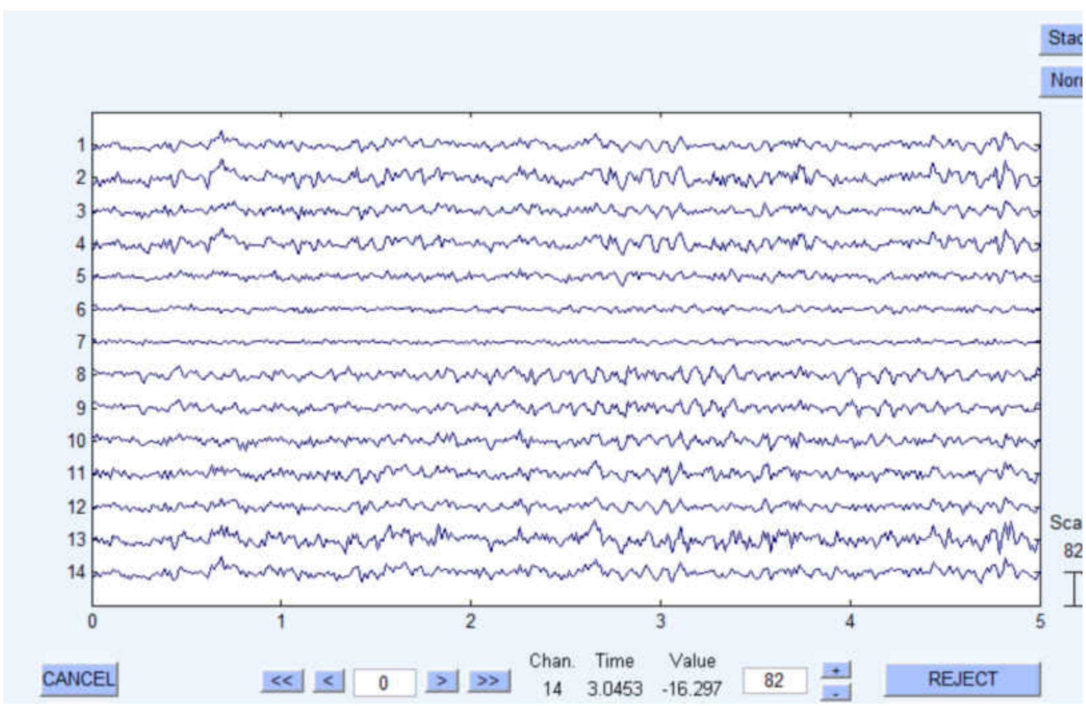


Figure 5-6 EEG data after artifact removal for same subject in same time frame

After artifact removal, the time domain data for each participant was divided into three sections: “Eyes Open”, “Eyes Closed” and “Training” as identified by the respective markers. The time domain signal for each participant in each section was transformed into frequency domain using Welch’s method. This method employed a Hanning window, segments of length 256 and 50% overlap. The power spectral density is obtained by computing and then averaging the periodograms of each segment (Sheikholeslami et al., 2007). The advantage of Welch’s method is that it reduces the noise in frequency domain by averaging. It is well known that the interpretation of results based on analysis of non-normalized powers (raw power data) is adversely affected by the power law (Cohen, 2014). Due to the power law, the power at higher frequencies is selectively reduced as compared to power at lower frequencies. Data affected by power law (raw power data) poses challenges in following: 1) visualizing power across different frequency bands, 2) quantitative comparison of power across bands, 3) comparing data across the subjects, and 4) distinguishing task related changes in power from background activity. In addition, the raw power values are not normally distributed. Hence, the normalization of signal was achieved using baseline of eyes closed and eyes open. Then the power in each of the bands; alpha, beta, theta and gamma were obtained for each participant for further comparative analysis.

Different software/programming languages are utilized for different phases of neural signal process. EMOTIV Testbench is used to record EEG signal of participants and to obtain signal file in csv format. MATLAB is used for artifact removal using wICA and Python is used to obtain normalized power spectral density. Then JMP, a statistical analysis software is used to analyze normalized power of participants in two trainings by applying t-test. It should be noted that the total amount of data for all participants exceeded 5 GB in .csv files. Large amount of data made it essential to use computationally efficient programming techniques such as vectorized array programming using Python packages such as NumPy and Pandas.

Data processing for EEG signal is summarized in figure 5-7

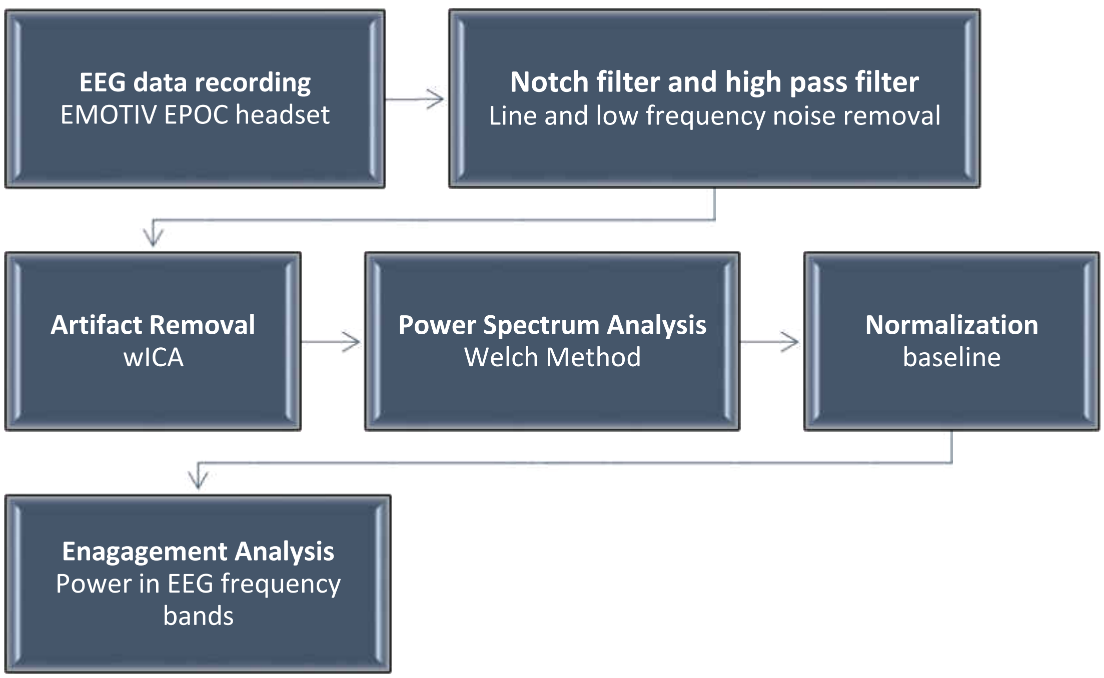


Figure 5-7 Flowchart of EEG data processing

5.4 Statistical Analysis

Beta band (13 Hz to 30 Hz) is considered to reflect activation of Cortex and is associated with increased level of concentration and task related engagement. Higher Beta also represents active processing. On the other hand, Alpha band is dominantly observed during state of relaxation/drowsiness in adults (Sherlin, Budzynski, Budzynski, Evans, & Abarbanel, 2009). When a person experiences higher engagement in a task, the attention, focus and concentration are observed to be increased. On the other hand; boredom, dullness, drowsiness or relaxed state is observed when a person is not actively engaged in a task. Beta to Alpha ratio increases during brain activation and decreases during brain deactivation (Navea & Dadios, 2015).

Therefore, ratio of power in Beta band to power in Alpha band was considered as a metric for task related engagement. The higher the value of this metric, higher would be the task related engagement and sustained attention experienced by participants. A two sample t-test (assuming unequal variances) was applied to this metric (ratio of power in Beta band to power in Alpha band) for virtual and slide based fire safety training to compare the engagement / attention levels (Hjelm & Browall, 2000; Lin & John, 2006).

CHAPTER 6 RESULTS

Results are described in following order:1) slide based fire safety training, 2) virtual simulation based fire safety training, 3) comparison between conventional and virtual simulation fire safety training, 4) EEG analysis. JMP statistical analysis software was used to analyze the data.

6.1 Conventional fire safety training

6.1.1 Demographics

A total of 73 participants were part of this study. Demographic data depicted in figures 6-1 shows distribution of age of participants in training per their age, profession and gender. 38 participants were in age group 21-25, 15 were in age group 26-30, 14 were 31-40 years old, 4 were 18 to 20 years of age while 2 participants were more than 40 years old.

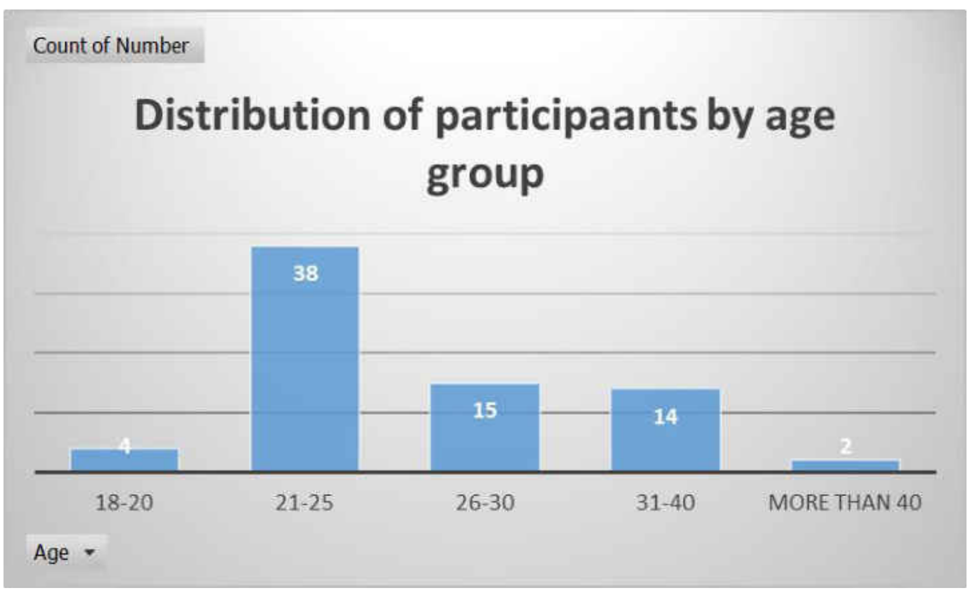


Figure 6-1 Distribution of participants of slide based training by age group

Figure 6-2 shows distribution of participants as per profession and gender. 44 participants were undergraduate students and 26 participants were graduate students. 46 were males while 27 were females, 1 participant was a faculty, and 2 were visitors.

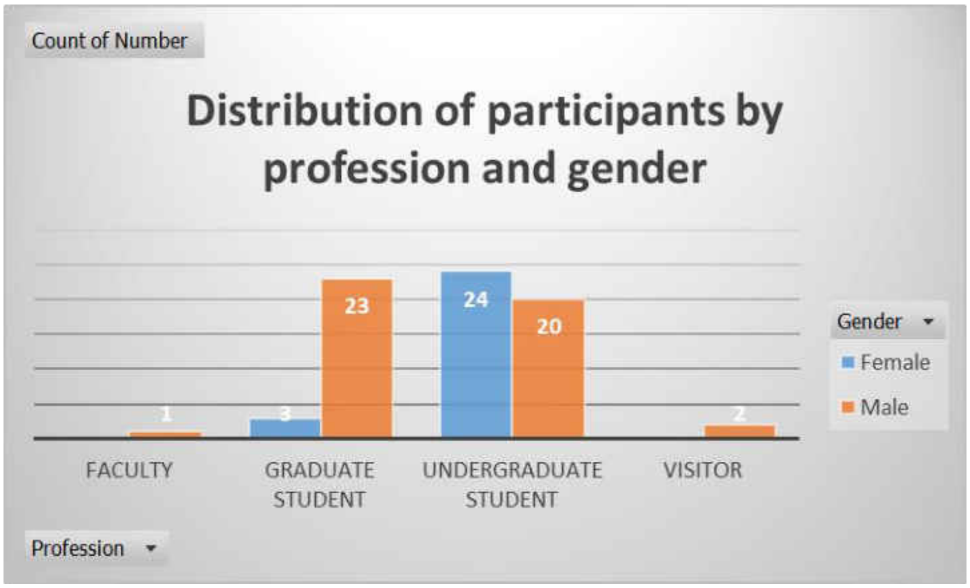


Figure 6-2 Distribution of participants by profession and gender

In demographic questionnaire, participants were asked "how relevant, to you, is the need to get trained on fire safety and emergency evacuation procedures?" Out of 73 responses, 32 participants thought fire safety training is relevant, 25 were neutral, and 8 responded it is very relevant. However, 5 participants thought it was irrelevant and 3 thought fire safety and emergency evacuation training is very irrelevant. Distribution is depicted in figure 6-3 below.

Figure 6-3 Relevance of fire safety training for participants

Another question on demographic questionnaire asked participants which type of emergency evacuation training they received in last year. Figure 6-4 shows responses of participants. 57 participants said that they did not receive any type of fire safety and emergency evacuation training. 7 received slides and video based training, 2 received in person lectures, and 6 received hands on training. During the interview process, experts said that students who live in dorms receive evacuation training once a semester and students who work as research assistants undergo mandatory safety training.

Figure 6-4 Types of fire safety training received by participants

Participants were asked about their familiarity on fire safety and emergency evacuation training, 19 participants were familiar with training, 20 were unfamiliar, 26 were neutral, 5 were very familiar and 3 were very unfamiliar as shown in figure 6-5.

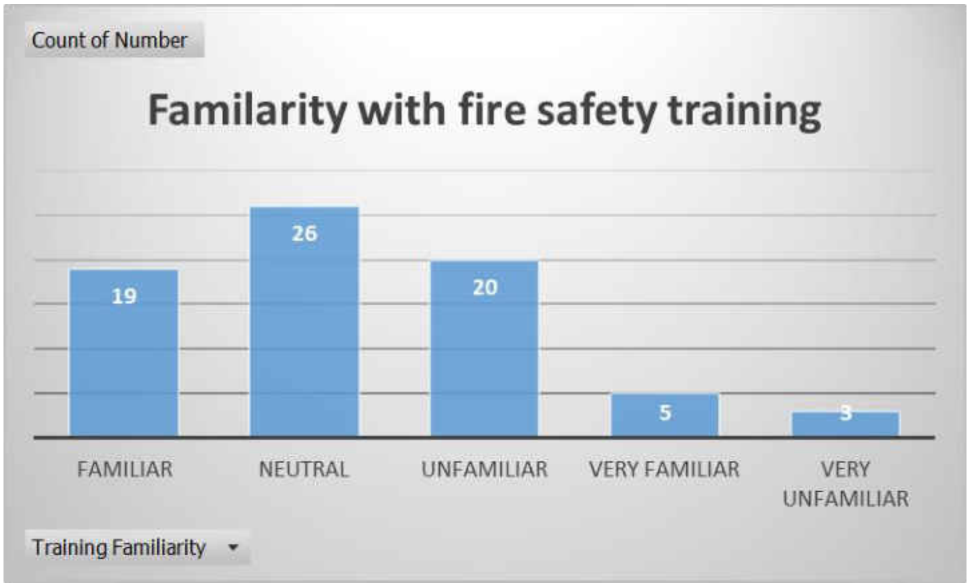


Figure 6-5 Familiarity of participants with fire safety training

Trainees were asked," how many times did they participate in an evacuation drill during last year." 51 of trainees did not participate in drill last year, 17 participated once and 4 participated 2-3 times as depicted in figure 6-6.

Figure 6-6 Frequency of fire safety training received by participants in last year

6.1.2 Knowledge test

73 participants completed a pre-test and a post-test. Average score of participants on pre-test is shown in figure 6-7. There were 4 questions each in knowledge, application and analysis category. Average score (out of 1) on knowledge category was 0.70, on analysis category was 0.48, and was 0.76 on analysis category.

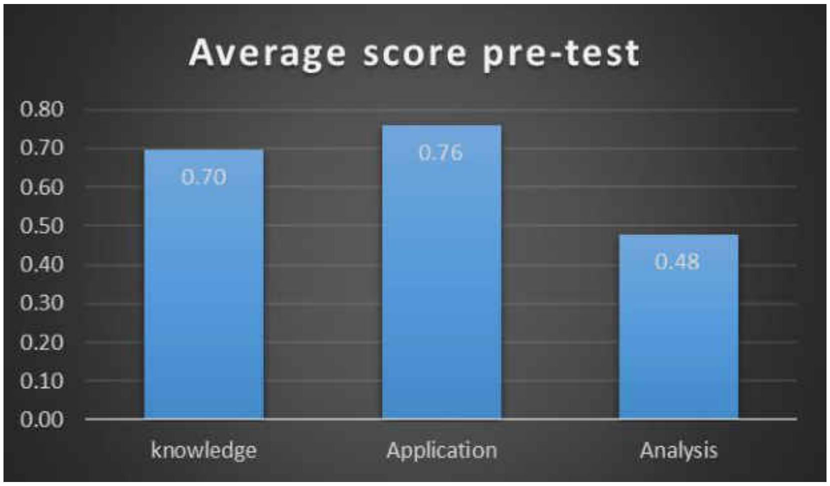


Figure 6-7 Average score of participants on pre-test for slide based training (out of 1)

After slide based training, average scores of participants out of 1 were 0.90 on knowledge category, 0.84 on application, and 0.68 on analysis category. Average score of participants on post-test is shown in figure 6-8.

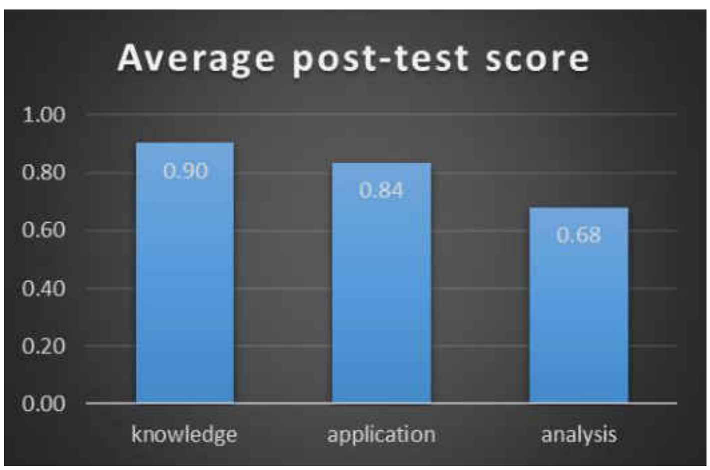


Figure 6-8 Average score of participants on post-test for slide based training (out of 1)

Paired t-test was applied to see if there is a statistically significant difference between knowledge on fire safety and emergency evacuation procedures before training and after training

From matched pair t-test applied to scores of pre-test and post-test, it can be said that training resulted in significant increase of post test scores (p-value 0.0001, α=0.05). It can be concluded that slide based training was effective in short term.

After 4 weeks of training, participants were requested to take a final knowledge test. From matched pair t-test it is evident that there was significant difference in pre-training and one month after training total test scores (p-value 0.0101, α=0.05). Thus, slide based training was effective in long term.

6.1.3 Engagement

Engagement questionnaire was provided after training and trainees rated each item on the scale of 1 to 5, (**1**-Strongly Disagree, **2**-Disagree, **3**-Neutral, **4**-Agree, **5**-Strongly Agree). Response of 72 participants for engagement questionnaire is shown in table 6-1.

It can be observed from the table that 22.22% participants strongly agreed that there was new information presented in training that they were not aware of. 19.44% strongly agreed that slide based training was an enjoyable experience. Majority (55.56%) of participants strongly disagreed that there was too much information in training. 14.08% trainees thought that they will retain contents after a month, 18.06% would like to undergo same training after a year and 23.61% said that their response to fire situation is modified after training.

Table 6-1 Engagement questionnaire result for conventional training

Likert scale	Questions on engagement						
	New information in training	Enjoyable experience	Too much information	Difficult to concentrate on contents	Retention after a month	Modified response	Same training next year
Strongly Disagree	**9.72%**	**12.50%**	**55.56%**	**58.33%**	**8.45%**	**2.78%**	**15.28%**
Disagree	**2.78%**	**4.17%**	**4.17%**	**8.33%**	**4.23%**	**2.78%**	**4.17%**
Neutral	**18.06%**	**27.78%**	**19.44%**	**15.28%**	**22.54%**	**15.28%**	**30.56%**
Agree	**47.22%**	**36.11%**	**16.67%**	**15.28%**	**50.70%**	**55.56%**	**31.94%**
Strongly Agree	**22.22%**	**19.44%**	**4.17%**	**2.78%**	**14.08%**	**23.61%**	**18.06%**

6.1.4 Time spent in training

Office Mix (OfficeMix, n.d.) has a data analytics capability that allowed to track time spent by user on every slide. Office Mix program failed to record time spent by 4 participants. However, for 68 trainees time data was recorded successfully. Figure 6-9 shows distribution of total time spent in seconds on 32 slides in fire safety training by each trainee. Mean time spent is 580.202 seconds with standard deviation of 315. 08 seconds.

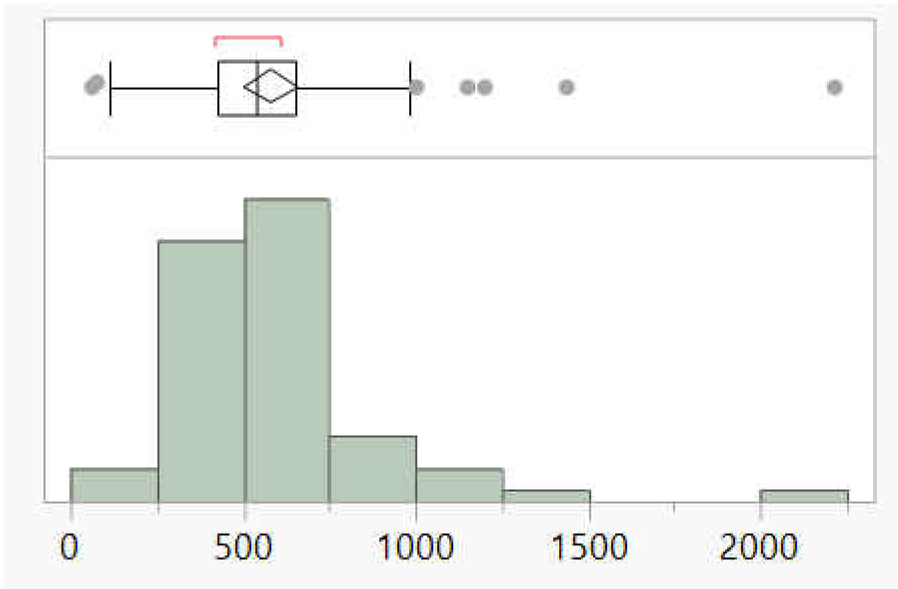


Figure 6-9 Histogram of total time spent by trainees on slides in fire safety training

Also, it was observed in data analytics that participants viewed slides only once. They did not choose to go back to slides to review concept before answering question on post knowledge test.

6.2 Virtual fire safety training

6.2.1 Demographics

70 participants underwent virtual simulation based fire safety training. On an average, trainees took about 40 minutes to complete the study. Distribution of participants by age group, gender and profession is shown in figure 6-10. 36 participants belonged to age group 21-25, 12 participants were in age group 26-30, 10 were 31-40 years old, 9 were 18 to 20 years of age and 3 were more than 41 years old.

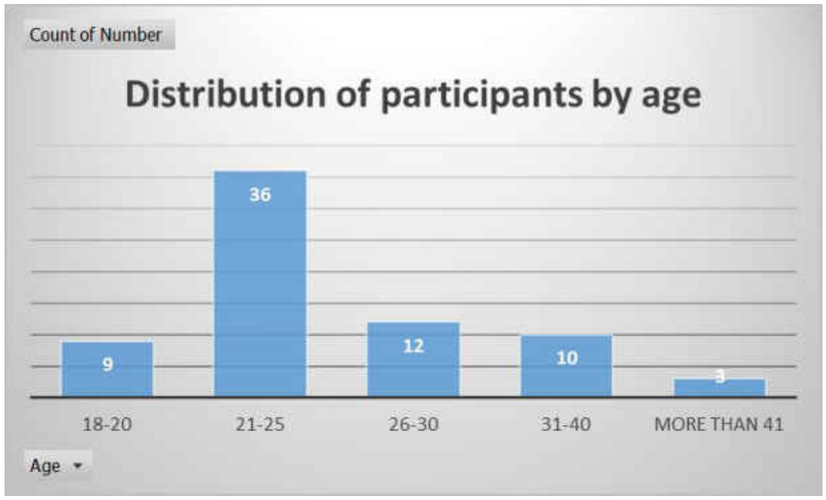


Figure 6-10 Distribution of participants by age for virtual fire safety training

There were 20 female participants and 50 male participants. 2 participants were visitors while rest were UCF graduate or undergraduate students, staff and faculty. Count of participants by profession and gender is shown in figure 6-11.

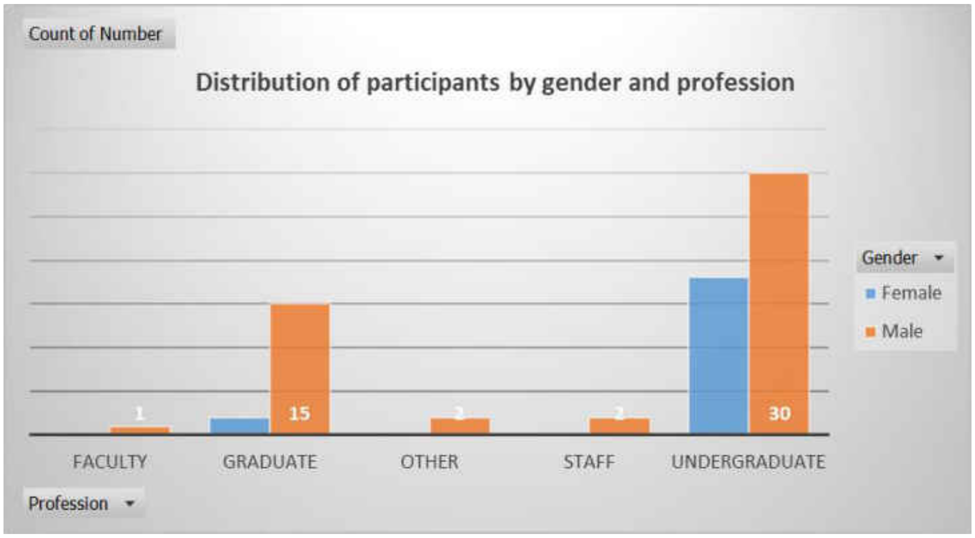


Figure 6-11 Distribution of participants by profession and gender for virtual fire safety training

Trainees were asked about familiarity with Engineering II building. 41 participants replied they were familiar with Engineering II building, 13 answered they were very familiar, 11 were neutral, 3 were unfamiliar and 2 students were very unfamiliar with real Engineering II building

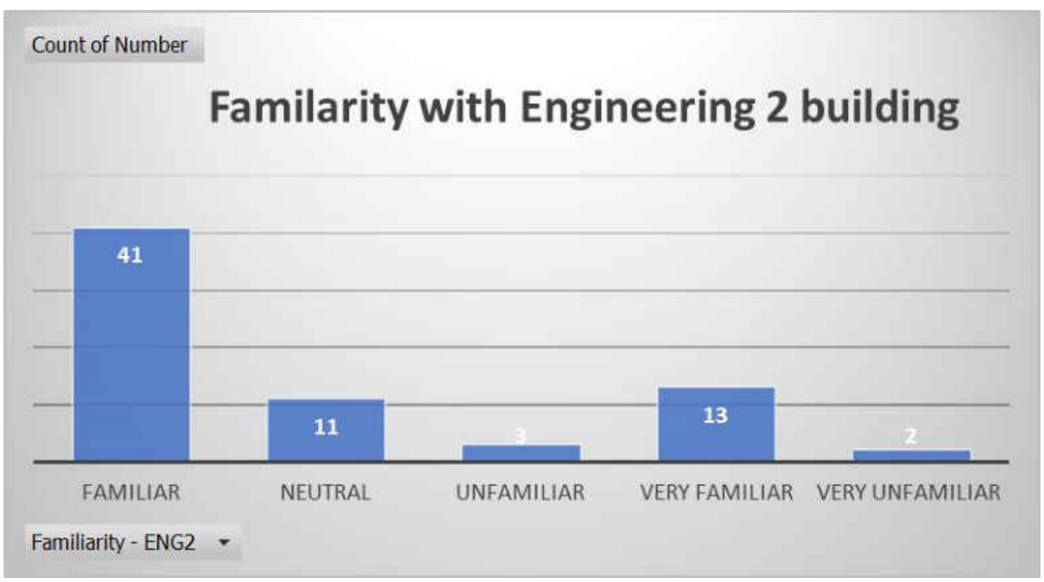


Figure 6-12 Familiarity of participants with Engineering II building

33 trainees answered relevant, 21 trainees were neutral, 9 trainees answered very relevant while 5 said irrelevant to the question "how relevant, to you, is the need to get trained on fire safety and emergency evacuation procedures?

Figure 6-13 Fire safety training relevance for participants of virtual training

Participants answered a question about their familiarity with the fire safety and emergency evacuation procedure. 24 students responded they were familiar, 23 students were neutral, 16 students were unfamiliar, 4 students were very familiar and 1 student was very unfamiliar.

Figure 6-14 Familiarity of trainees with fire safety training

50 trainees replied that they did not undergo any fire safety or evacuation emergency training in last year. 3 participated in hands on training, 8 participated in computer based training, 3 received lecture on fire safety and 4 participants received multiple types of training like lectures, slide based and hands on training.

Figure 6-15 Types of fire safety training received by participants last year

49 students answered that they never participated in fire drill in last year. 12 trainees participated once in a fire drill over last year while 7 participated 2-3 times.

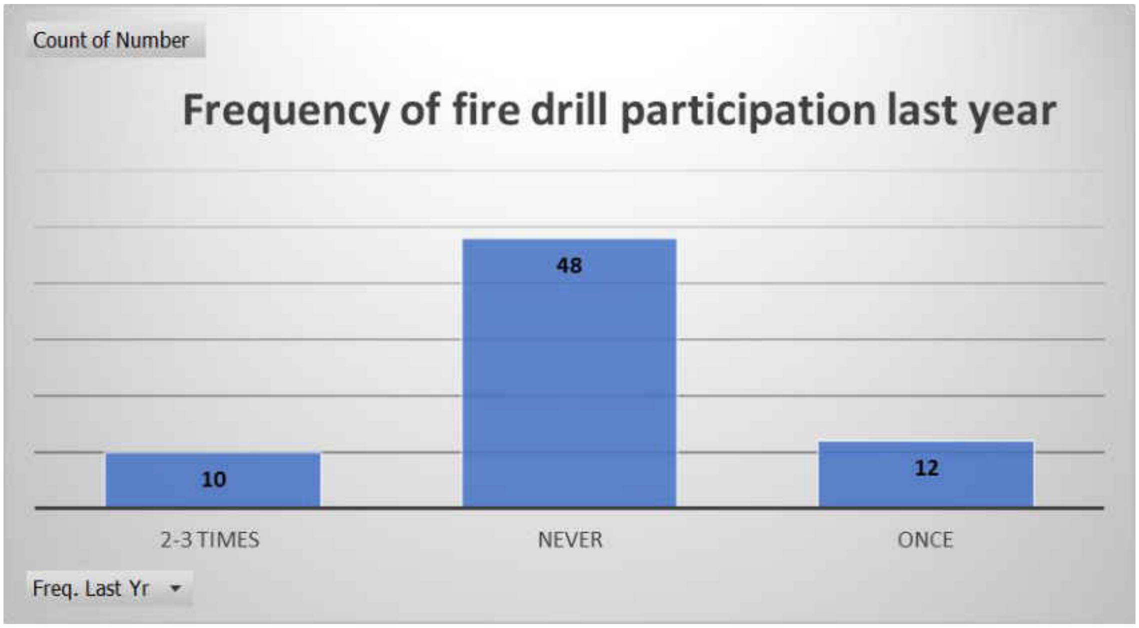


Figure 6-16 Frequency of participation in drill last year

To understand ease of operation while participants interact with video or virtual games on computers, they were asked a question to identify their comfort level with video games. 23 trainees were very comfortable, 23 were comfortable, 16 were neutral, 4 were uncomfortable while 2 were very uncomfortable as depicted in figure 6-17.

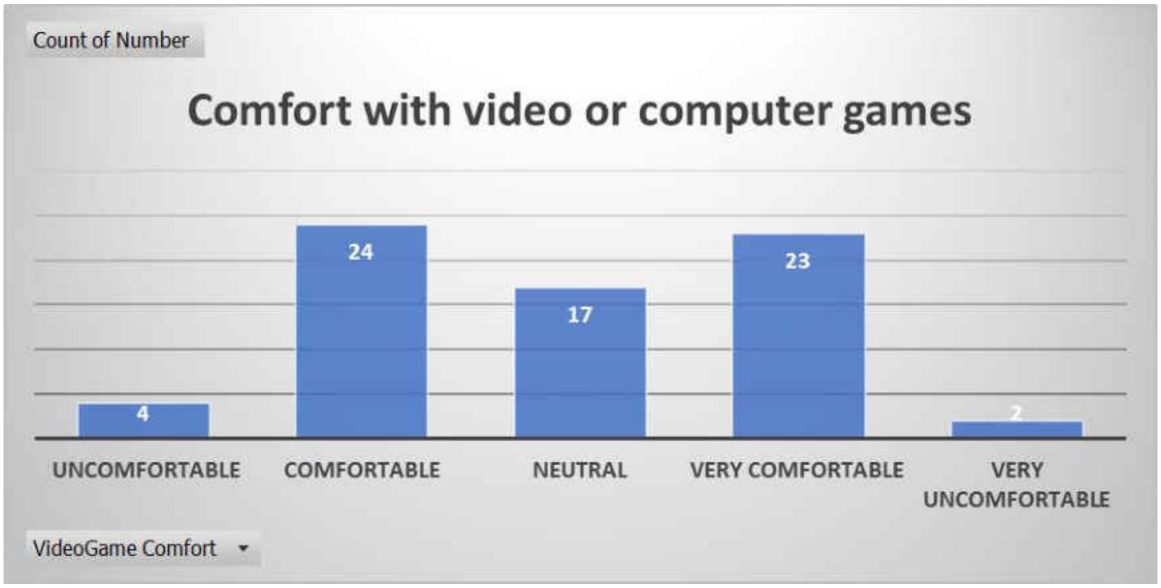


Figure 6-17 Comfort with playing video or computer games

Figure 6-18 shows response of participants of virtual fire safety training to question on how frequently do they play video or computer games. 8 participants responded never, 20 play yearly, 17 play monthly, 19 play weekly and 4 play every day.

Figure 6-18 Frequency of playing video or computer games

6.2.2 <u>Knowledge test</u>

Average scores of pre-test and post-test of 70 participants from virtual training is reported in this section. Average score of participants (out of 1) on pre- test was 0.63 on knowledge, 0.73 on application and 0.47 on analysis category as shown in figure 6-19.

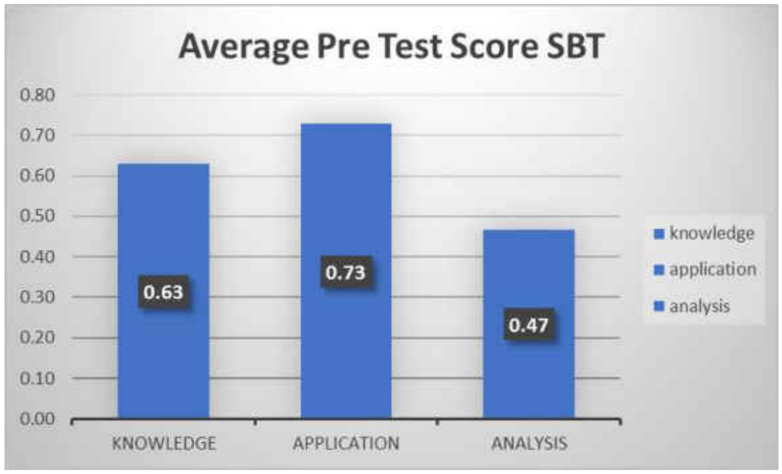


Figure 6-19 Average pre-test score on virtual fire safety training

Average score of participants (out of 1) on post-test was 0.94 on knowledge, 0.79 on application and 0.60 on analysis category.

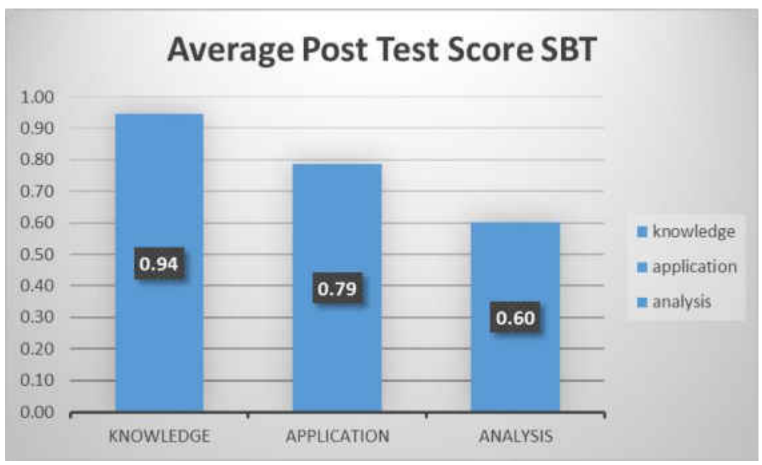


Figure 6-20 Average post-test score on virtual fire safety training

Paired t-test was applied to knowledge test scores of trainees before training and immediately after training. Results of the t-test showed that 3D virtual training had significant effect on increase in post-test scores (p-value 0.0001, α=0.05). Thus, 3D virtual fire safety training had a short-term effectiveness.

Trainees were requested to take a final knowledge test after 4 weeks from training. Matched pair t-test applied to pre-test and final test scores showed significant difference in the scores (p-value 0.0001, α=0.05). Thus, there was an increase observed in final scores as compared to pre-test scores showing long term training effectiveness.

6.2.3 Simulator sickness

Total score for simulation sickness was calculated for all the participants of 3D virtual safety training. Mean is 5.877 with standard deviation of 10.29 as shown in figure 6-21.

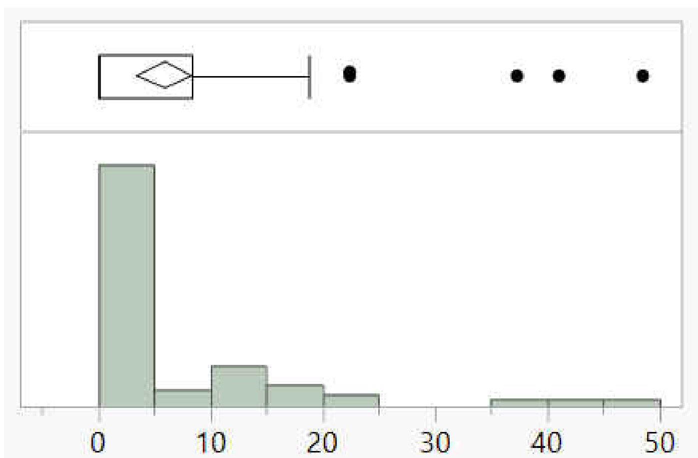


Figure 6-21 Histogram of SSQ total score of 70 participants

However, 3 data points were observed to have very high SS value (48.62, 41.14 and 37.4). It was observed that 3 participants who had highest total SS score also had highest Oculomotor subscale value (8, 6, and 5 respectively). Oculomotor subscale refers to symptoms of fatigue, headache, eyestrain, and difficulty focusing. Two participants reported difficulty in focusing, concentrating which resulted in high SSQ. As none of the questionnaire captured level of fatigue before participation in experiment, it cannot be corroborated with evidence whether participants felt overall fatigue that reduced their focusing ability or fatigue was induced during training. One of the three participants reported eye strain and blurred vision and this participant responded to questions about computer games as “never play computer games and being very uncomfortable with computer/video games”. Thus, these 3 data points were considered as outliers.

After removing outliers, and again plotting data in JMP (figure 6-22), mean of total score of participants is 4.24 with std. dev. 6.825. This mean score of SSQ total score indicates fire safety virtual simulation had negligible symptoms on participants.

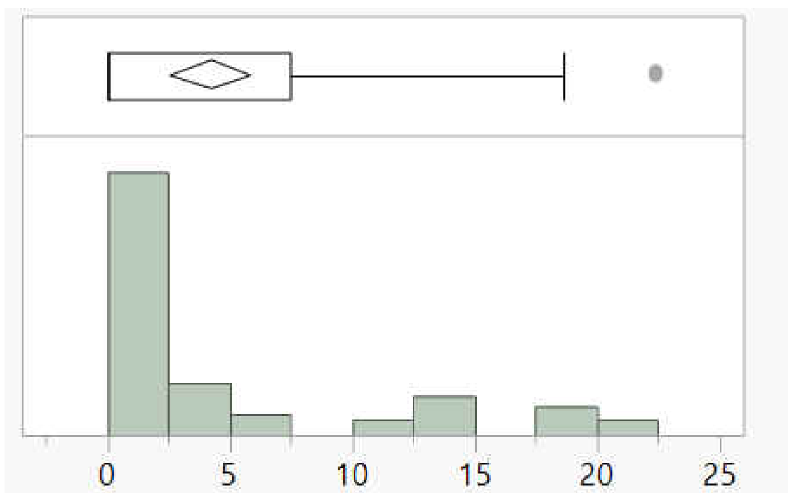


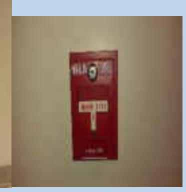
Figure 6-22 Boxplot after removing outliers

6.2.4 Fidelity

Fidelity and engagement questionnaires were provided at the end of the training. Fidelity related questions were asked about quality of objects displayed in virtual environment. Questions in fidelity questionnaire are shown in table 6-2. Engagement related questions focused on experience and concentration in the game. Trainees were asked to rate questions on the scale of 1 to 5 (**1** - Strongly Disagree, **2** - Disagree, **3**- Neutral, **4**- Agree, and **5** - Strongly Agree). Average score of

70 participants of 3D virtual fire safety and emergency evacuation training on fidelity questionnaire and results are tabulated below

Table 6-2 Fidelity Questionnaire

Question number	Description
Q1	Introductory exercise helped you to familiarize with the controls and navigation
Q2	It was easy to navigate in the virtual Engineering II building.
Q3	The picture shown on the left from the training resembles that on the right from real life  
Q4	Your familiarity with the escape routes and emergency exists of Engineering II building has increased after training.
Q5	The demonstrated safety equipment shown in the training resembles that from real life    
Q6	The elements depicting fire (smoke, flames, etc.) resembled those that might be seen in real life.
Q7	The scenario depicting fire alarm situation resembled what might feel like in real life
Q8	The simulation helped you to connect better with the potential real life scenarios.

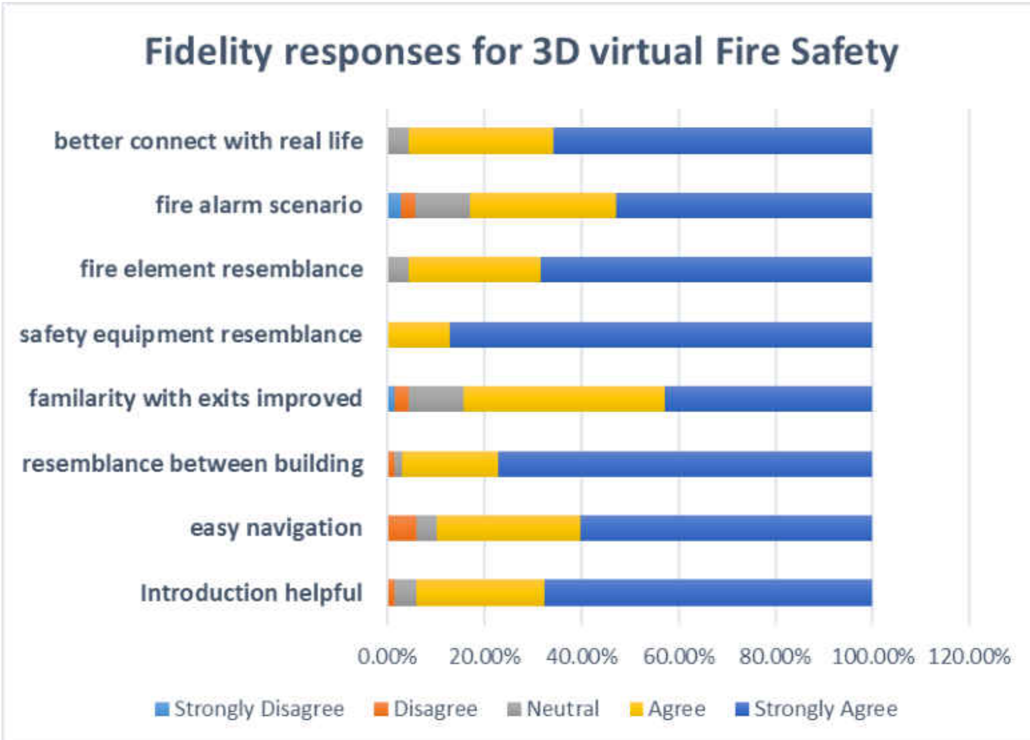


Figure 6-23 Responses to fidelity questionnaire

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Strongly Disagree	0.00%	0.00%	0.00%	1.43%	0.00%	0.00%	2.86%	0.00%
Disagree	1.47%	5.88%	1.52%	2.86%	0.00%	0.00%	2.86%	0.00%
Neutral	4.41%	4.41%	1.52%	11.43%	0.00%	4.29%	11.43%	4.29%
Agree	26.47%	29.41%	19.70%	41.43%	12.86%	27.14%	30.00%	30.00%
Strongly Agree	67.65%	60.29%	77.27%	42.86%	87.14%	68.57%	52.86%	65.71%

Figure 6-24 Responses for each question on fidelity questionnaire

Response of trainees to fidelity questionnaire as shown in figures 6-23 and 6-24 made it clear that participants found 3D virtual Engineering II building environment comparable to that of real Engineering II building. 77.27% trainees strongly agreed and 19.70% agreed to question 3. Also, 87.14% participants strongly agreed and 12.86% agreed that fire safety equipment was similar to that seen in real life 52.86% strongly agreed while 30% agreed that fire alarm situation of finding exit in emergency resembled to real life situation. Thus, it is validated that fidelity of virtual 3D engineering building, safety equipment and fire components closely resembled reality.

6.2.5 <u>Engagement</u>

Engagement questionnaire was provided after training and trainees rated each item on the scale of 1 to 5, (**1**-Strongly Disagree, **2**-Disagree, **3**-Neutral, **4**-Agree, **5**-Strongly Agree).

Following figure shows responses expressed in terms of percentage by 70 participants who underwent virtual fire safety and emergency evacuation training.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The training material had significant new content that you were not aware of	2.86%	4.29%	5.71%	44.29%	42.86%
The training experience was fun and enjoyable	0.00%	0.00%	7.14%	32.86%	60.00%
The training seemed to have too much information and it failed to maintain your attention	48.57%	27.14%	12.86%	5.71%	5.71%
It was difficult to concentrate on training material and you felt distracted	57.14%	30.00%	5.71%	5.71%	1.43%
You are likely to remember most of the key concepts presented in training a month from now.	0.00%	2.86%	10.00%	58.57%	28.57%
Taking this training has modified your likely response to a real life fire / emergency evacuation situation	1.43%	1.43%	11.43%	38.57%	47.14%
You would like to undergo same fire safety and evacuation training next year	4.29%	7.14%	22.86%	25.71%	40.00%

Figure 6-25 Engagement questionnaire results

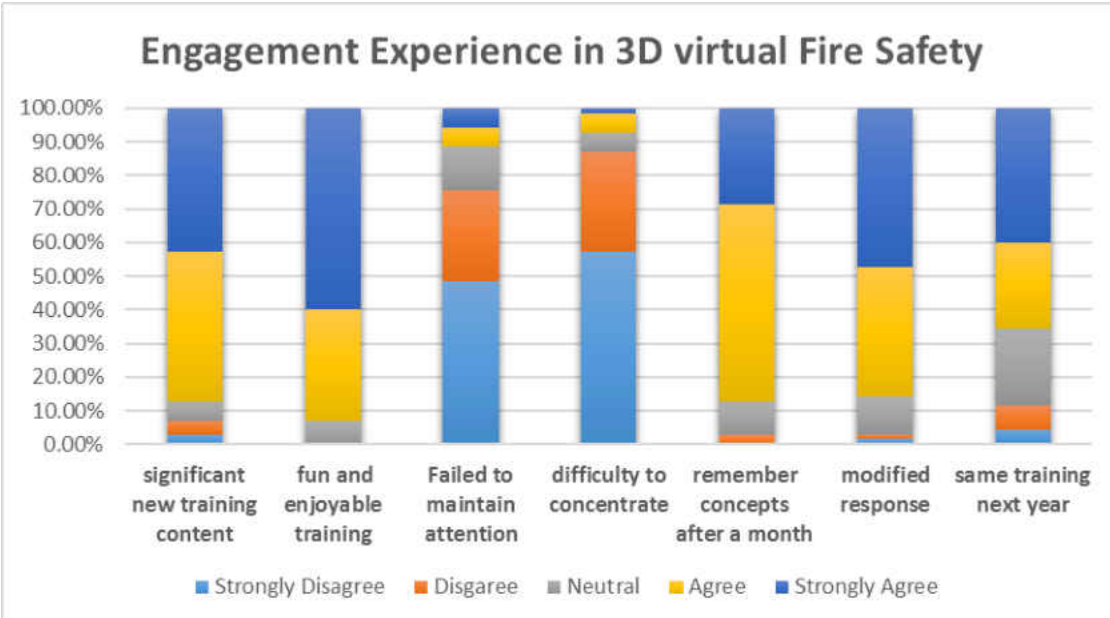


Figure 6-26 Result of engagement questionnaire for virtual training

From results of engagement questionnaire depicted in figure 6-24 and 6-25, it is evident that participants thought new contents were presented in this training, it was a fun and enjoyable experience and they would like to undergo same training next year. Thus, 3D virtual fire safety training was perceived engaging by participants.

6.2.6 Transfer of training

The three factors that are considered important to understand transfer of training in virtual environment are – 1) fidelity assessment by experts, 2) Overall trainee experience, and 3) performance assessment (Garrett & McMahon, 2013).

Performance assessment

Present work was developed as an environment for practice and thus did not program algorithms to measure performance in terms of trainees finding nearest exit, time taken to find exit, etc.

However, fidelity assessment and overall trainee experience was used to measure inverse transfer of training.

Fidelity assessment of experienced participants

Experienced participants and experts who participated in case study were asked about how similar did they find virtual 3D fire safety world to real Engineering II environment. Participants who responded in demographic questionnaire that they were familiar or very familiar with fire safety and emergency evacuation procedures and had received fire safety training last year are considered as experienced participants.

Responses of experienced participants on 5 point Likert Scale (figure 6-27) suggest that 3D virtual fire safety and emergency evacuation represented environment, scenarios and safety equipment accurately as of real world. Specific feedback from experienced participants helped to understand what are some of the aspects that could be improved. Real fire alarm sound was recorded during one of the drills and was incorporated in virtual world to maintain fidelity. But, experienced participants thought that alarm in virtual world doesn’t sound as sharp and loud as it does in real world. In fire alarm scenario, one of the most important inputs was that lights in fire alarm start flashing when alarm goes off. Present virtual training is developed as an environment for practice for individuals. Another difficulty level could be added where there are many other avatars trying to exit from same way and there is chaotic situation as of real world during emergency.

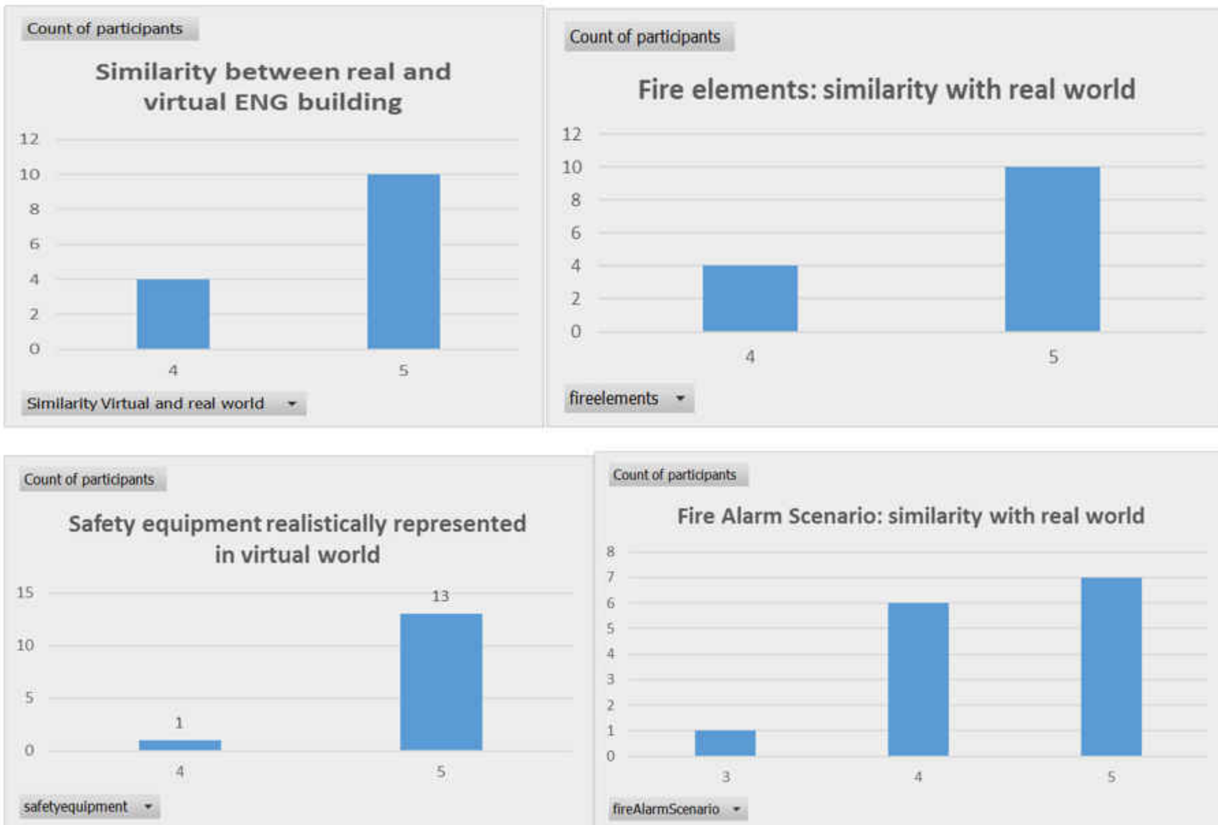


Figure 6-27 Experienced participant's response for similarity between virtual and real world

Trainee Opinion

All the trainees were provided with fidelity and engagement questionnaires. Questions on this questionnaire are categorized in four categories –

1) Represented fire safety and evacuation procedure (fidelity questions 3, 5, 6 and 7)

2) Improved real world performance (questions 3 and 8 fidelity questionnaires, question 6 engagement)

3) Valuable training tool (question 5, 7 engagement)

4) Necessary features for training (questions 1 and 2 fidelity questionnaire)

In total, 14 Experienced and 56 non- experienced trainees responded to questionnaire. Agree and strongly agree responses are summarized for above four categories as shown in figure 6-28.

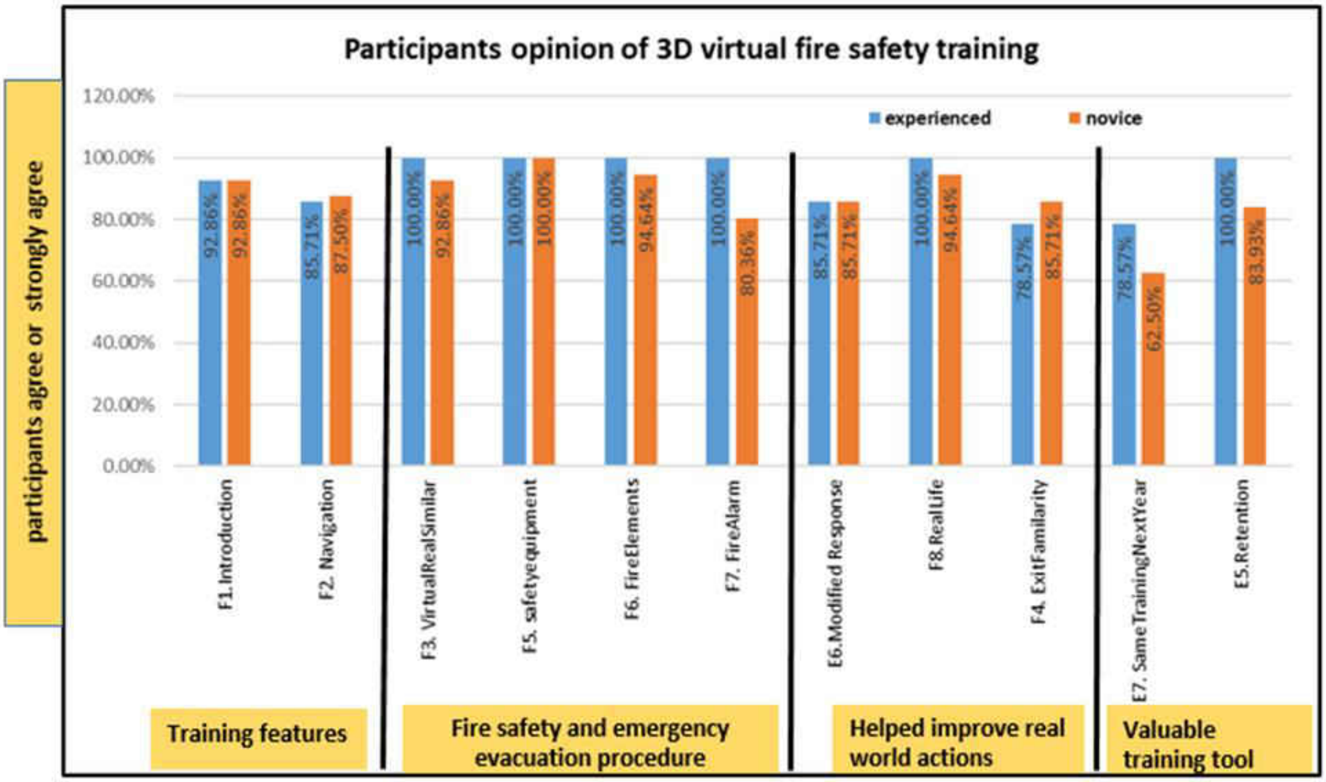


Figure 6-28 Trainee opinion: inverse transfer of training

It can be seen in figure 6-28 that not only novice participants but also experienced participants found 3D virtual fire safety and emergency evacuation platform viable for training people. Therefore, this platform can be used to provide basic training on fire safety and emergency evacuation to students, employees and residents of varying level of experience and familiarity.

6.2.7 <u>Time spent in training</u>

A computer program was written to save time stamps when trainees clicked on any task to a database. After training, it was possible to retrieve time stamps of each clicked task and calculate total time spent on completing tasks in virtual fire safety training for each trainee. However, one of the trainees did not enter his/her email id in simulation which resulted in failure of retrieving time spent by that trainee on tasks in virtual training. Following histogram (figure 6-29) shows total time spent in seconds by 69 trainees in 3D virtual environment.

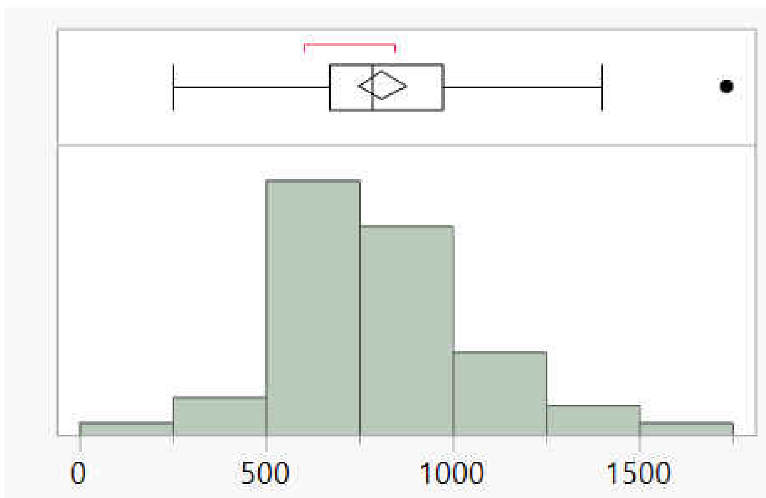


Figure 6-29 Total time spent by trainees in virtual fire safety training

Mean time spent by trainees in virtual fire safety and emergency evacuation training was 813.6 seconds with standard deviation of 257.6 seconds. In calculating this time, only time spent on attempting 15 tasks is considered. Time spent in introduction area, navigation or watching videos is not included.

6.3 Comparison between slide based and virtual fire safety training

6.3.1 Knowledge Test

Participants were provided with a pre-knowledge test that asked 12 questions on fire safety and emergency evacuation. Purpose of the pre-test was to capture knowledge baseline of participants. They were asked to take the best guess for answering questions that they didn't know. Some of the participants left questions unanswered in case they did not know the concept. Same test with change of sequence of answer options and/or questions were provided as a post and final tests. After collecting answers for all 3 tests for all the participants, the correct answer to each question was credited 1 point while wrong or blank answer was credited 0 point. Hence, maximum score possible on pre, post, and final knowledge test was 12.

6.3.1.1 Short term effectiveness

To compare short term effectiveness of slide based and 3D virtual fire safety training two sample t-test was applied. Score of participants on knowledge test before and after training showed no significant difference between slide based and 3D virtual training (p-value: 0.2437).

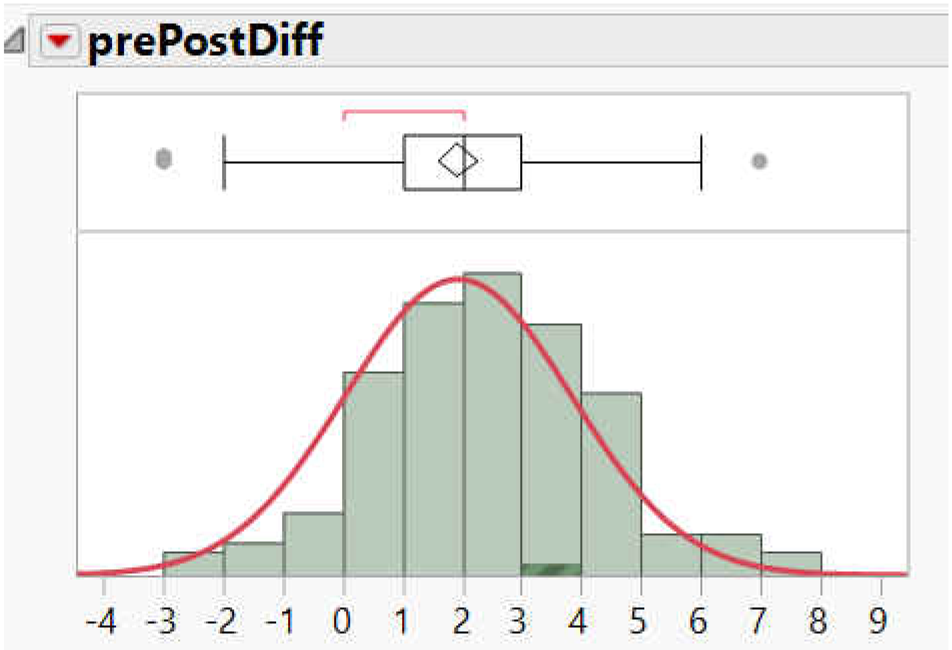


Figure 6-30 Histogram of difference between pre and post scores for all trainees

6.3.1.2 Long term effectiveness

95 participants responded to final knowledge test after a month from initial training intervention. Two sample t-test was applied to test hypothesis that long term effectiveness of virtual fire safety training will be better than slide based training. Null hypothesis that there is no difference between virtual and slide based training test score before training and one month after training is rejected at alpha=0.05 with p-value 0.0262.

6.3.2 Engagement questionnaire

Engagement questionnaire utilized Likert scale to understand experience of trainees in virtual and conventional fire safety training. As the scoring was ordinal, a non-parametric test (Wilcoxon Rank Sum) was used to test the hypothesis.

As shown in table 6-3, concepts presented in virtual training were more engaging than that of slide based training. Virtual training was a fun and enjoyable experience as compared to slide based training. Participants felt none of the training had too much information and it was not difficult to concentrate. Participants reported that they would like to undergo virtual training next year and it has modified their response to emergency situations better than that of slide based training.

Table 6-3 Engagement questionnaire statistical analysis

Description	Wilcoxon Test Results (α =0.05)
The training material had significant new content that you were not aware of.	P =0.0021 SBT better than PPT
The training experience was fun and enjoyable.	P=0.0001 SBT better than PPT
The training seemed to have too much information and it failed to maintain your attention.	P=0.7667 Trainings were comparable
It was difficult to concentrate on training material and you felt distracted.	P=0.3818 Trainings were comparable
You are likely to remember most of the key concepts presented in training a month from now.	P=0.0009 SBT better than PPT
Taking this training has modified your likely response to a real life fire / emergency evacuation situation.	P=0.0079 SBT better than PPT
You would like to undergo same fire safety and evacuation training next year.	P=0.0062 SBT better than PPT

6.3.3 Time Spent in training

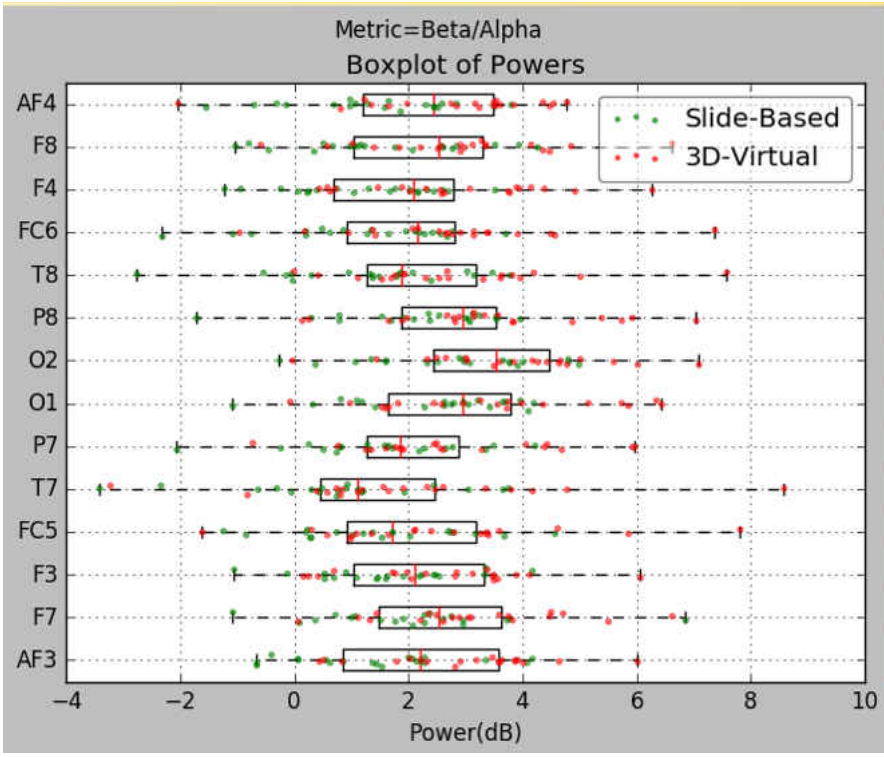
Trainees in slide based training and virtual training were told that they can spend as much time as they want in training. There was no limit on how many times they revisit slides/ scenarios in training. Data for time spent (in seconds) on training slides and tasks performed in virtual simulation was collected and analyzed. Two sample t-test revealed that time spent by trainees in virtual simulation training was significantly more than time spent by trainees in slide based training (p-value 0.001, alpha = 0.05)

6.4 EEG results for engagement

Neural signal powers in various frequency powers of 20 participants from slide based training and 20 participants from 3D virtual training were compared. Beta to Alpha frequency band power ratio was calculated for all 14 channels and statistically compared using one sided t-test to see sustained attention of trainees in virtual training vs slide based training.

Baseline was chosen as eyes closed for normalization of power spectrum. Mean power of individual channel was used as averaging technique for this analysis. Ratio of Beta frequency band power to alpha frequency band power was used as an engagement index.

As shown in figure 6-31, p-value obtained from t-test for all 14 electrodes shows that ratio of power in beta to alpha bands is higher for 3D virtual training than slide based training at alpha=0.05. Thus, it can be concluded that attention and focus level experienced by participants in 3D virtual training is higher than conventional training.



Channels	p-value SBT>PPT
AF4	0.004
F8	0.005
F4	0.0009
FC6	0.0039
T8	0.0039
P8	0.017
O2	0.0232
O1	0.0418
P7	0.0121
T7	0.0473
FC5	0.0432
F3	0.0213
F7	0.0264
AF3	0.0009

Figure 6-31 Boxplots of power in beta to alpha ratio

CHAPTER 7 CONCLUSIONS

This research has developed a framework for 3D virtual fire safety and emergency evacuation training for residents of building which allows people to visualize their usual surroundings and emergency they may face in that environment. This virtual world based training allows interaction with various fire safety related equipment and scenarios such as finding nearest exit in case of emergency using a standard desktop computer, mouse and keyboard for students, employees or residents of buildings.

Scientific approach was utilized in development of every layer in training. Lean Startup methodology and existing literature was utilized to develop training contents. Slide based training was reviewed by two experts. 3D model of an engineering building, scenarios on fire safety and emergency evacuation, method of feedback and data logging were developed and were reviewed by an expert on virtual worlds. After incorporating suggestions of experts, developing assessment instruments and obtaining IRB approval, a case study was conducted with university students, EHS experts, faculty and staff.

Interviews of stakeholders of fire safety and emergency evacuation training conducted using Lean Startup method formed the baseline of this research study. Industry experts showed concern about capability of 3D virtual simulation in imparting same amount and type of knowledge as it is currently provided using conventional slide based training. Therefore, a conventional slide based training and 3D virtual training were developed based on same contents and compared on various factors like short and long term effectiveness, and engagement. Results of the case study validated that 3D virtual training can not only provide same knowledge as of slide based training but do so in more engaging manner. Moreover, its long-term effectiveness is proven to be better than conventional slide based training.

Negligible simulation sickness and high fidelity experienced by participants of 3D virtual training validated its effectiveness for training. Subjective and objective measurement of experience of participants on 3D virtual and slide based training performed using EEG recording showed that participants exhibited better sustained attention and focus while undergoing 3D virtual training as compared to conventional slide based training.

Literature review depicted the importance of adding intelligent agents in virtual fire safety simulator for guidance, social interaction or distraction (Ribeiro et al., 2013; Smith & Ericson, 2009).Thus, presence of non-player characters was successfully implemented in this virtual training that helped trainees in obtaining guidance and providing social sense.

This research provides further evidence that occupants of a building can be trained on same fire safety and emergency evacuation content in more engaging and effective manner using interactive 3D virtual world as compared to conventional slide based training which is consistent with the findings of Sacks et al. (2013) for construction workers safety and firefighter safety training study of Wener et al. (2015).

7.1 Contribution

This research developed a holistic, systematic and practical system for 3 D virtual fire safety and emergency evacuation training with different layers such as content creation, 3D virtual model development, trainee interaction, data logging, feedback method and validation.

Safety training is essential to prepare workers, employees and students for emergency situations. This research work provides a novel way of providing fire safety and emergency evacuation training in 3D virtual world. As trainees are able to visualize their usual surroundings- school building in this case, they are able to connect with EXIT ways and fire safety concepts and equipment in a better way. Interaction with industry and university experts made it evident that if people are provided with portable, flexible and experiential learning they can learn from it according to their own pace and convenience. Also, literature depicts that slide based training, popularly utilized in organizations for providing training is portable and flexible in nature but it lacks component of interactive learning (Horton, 2000; Jin & Nakayama, 2013). 3D virtual training has capability of providing experiential learning as well as it can easily accommodate team based activities and interaction.

This is a multidisciplinary research that has contributed to modeling and simulation, human factors and safety engineering along with industrial engineering. This research designed and developed a training system based on requirements of major stakeholders, validated this training on factors like effectiveness, and engagement. Also, effects on human in terms of simulation sickness, attention and fidelity were validated.

EEG has been utilized by researchers to measure effect of music on emotions or mood (Dong et al., 2010; Navea & Dadios, 2015), effectiveness of driving simulators (Li et al., 2013), influence of video games on adolescents (Lianekhammy, 2014), response to marketing stimuli (Khushaba et al., 2013). This is the first fire safety and emergency evacuation research that has explored attention and focus of trainees in 3D virtual vs slide based fire safety and emergency evacuation training by employing physiological measure - an EEG recording. This objective measurement has made it possible to understand how engagement and attention of trainees differed in virtual vs slide based training.

In summary, this work provides scientific foundations for organizations and researchers to develop more engaging and effective fire safety and evacuation training. EHS expert reviewers advocated that this training can provide a very good second-hand experience to students before they are engaged in hands on in person training. Thus, this virtual 3D training can be utilized to train residents on basics of fire safety and emergency evacuation without any state of the art equipment in engaging manner. In long term, such training has potential to enhance decision making capability of individuals in case of emergency and thus improve human safety, reduce the harm to personnel and property.

7.2 Future Work

Feedback obtained from reviewers and participants of training shaped future work direction. Present training is modeled on 4^{th} floor of virtual building. Other floors can be utilized to add different difficulty levels and scenarios. When a trainee is going through a scenario asking if he would fight or flee in this case and if the correct response is fight, he should be asked to grab nearest extinguisher and follow method of using fire extinguisher correctly. Increasing difficulty levels can be used to measure workload experienced in virtual training by employing EEG.

Multiple player training is another advantage of this virtual world based fire safety training. Though in this research work students participated in teams, more focus was on individual learning of concepts. Participants were not asked to solve the problem as a team. However, this virtual environment can be modeled for a team comprising of personnel with different organizational roles such as a professor or lab supervisor, a research assistant, graduate and undergraduate students. Scenarios can be developed around decision making and problem solving and an assessment metric can be implemented to understand dynamics of team performance.

In this training, time taken by trainees to find the exit way is not recorded as this is the training environment developed for people to practice at their own pace. However, in future, after a group of trainees undergo basic virtual training fire safety training session, they can be asked to take another training session where they are just asked to find nearest exit as fast as they can.

Performance of a trainee in the 3D virtual and fire safety training can be measured in advanced simulation levels. So, participants could practice concepts in presented basic level of virtual training and can then perform against pressure of scenarios such as time constraint of finding exit. This performance assessment can then be added to inverse transfer measure of training.

Eye tracking can identify where a participant is looking, dilation of pupils and eye blinks. Factors such as attention and focus are important in defining user's engagement. Eye tracking can be employed along with EEG to measure eye blinks and eye movements to understand participant's focus and attention in virtual world training. Also, removal of artifacts resulting from eye movements in EEG signal would become easy due to use of eye tracking.

The total amount of structured EEG data collected for 40 participants was of the order of 5 GB. As the number of participants and duration of training increase, it will be essential to develop systems based on advanced data analytics for handling the big data. Also, for seamless integration of various data processing steps such as denoising, power spectral analysis and plotting, the analytics will be developed on single platform. This will also enable real time plotting of the power spectral density during and immediately after the experiment to provide timely feedback to the researchers and participants. A program for denoising that is more computationally efficient than wICA will be developed. A program will be developed for automatic generation of markers in

EMOTIV as the participant performs various tasks in training. Also, various engagement metrics and performance metrics other than Beta/Alpha and power levels in various bands will be computed automatically, in real time using the big data analytics platform. Eventually, the goal is to be able to show participants their engagement levels in the task in real time which can act as a motivator to improve the task performance.

APPENDIX A
IRB APPROVAL

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Sayli Chandrashekar Bhide and Co-PI: Luis C. Rabelo**

Date: **February 22, 2016**

Dear Researcher:

On 02/22/2016, the IRB approved the following human participant research until 02/21/2017 inclusive:

Type of Review:	UCF Initial Review Submission Form
Project Title:	Fire Safety and Emergency Evacuation Training
Investigator:	Sayli Chandrashekar Bhide
IRB Number:	SBE-16-12056
Funding Agency:	
Grant Title:	
Research ID:	N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form cannot be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 02/21/2017, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

APPENDIX B
IRB APPROVAL ADDENDUM

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Sayli Chandrashekar Bhide and Co-PI: Luis C. Rabelo**

Date: **May 25, 2016**

Dear Researcher:

On 05/25/2016, the IRB approved the following minor modifications to human participant research until 02/21/2017 inclusive:

Type of Review: IRB Addendum and Modification Request Form
Modification Type: In phase 2 of the study participants' EEG data will be recorded to understand engagement of participants in the fire safety training. A revised protocol has been loaded in iRIS. Two Informed Consent documents have been approved: one for Simulation based training and one for Conventional power point training.
Project Title: Fire Safety and Emergency Evacuation Training
Investigator: Sayli Chandrashekar Bhide
IRB Number: SBE-16-12036
Funding Agency:
Grant Title:
Research ID: N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form cannot be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 02/21/2017, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Page 1 of 2

Signature applied by Joanne Muratori on 05/25/2016 02:57:26 PM EDT

IRB Manager

APPENDIX C
ASSESSMENT INSTRUEMENTS

Demographic Questionnaire

Check all that apply. Please answer each of these questions to best of your ability.

Please provide best email id to contact you	
Age	☐ 18-20 ☐ 21-25 ☐ 26-30 ☐ 31-40 ☐ more than 41
Gender	☐ Male ☐ Female ☐ Prefer not to answer
Profession at UCF	☐ Undergraduate Student ☐ Graduate Student ☐ Staff ☐ Faculty ☐ If other, Please specify_______________
How familiar are you with Engineering II building?	☐ Very unfamiliar ☐ Unfamiliar ☐ Neutral ☐ Familiar ☐ Very familiar
How relevant, for you, is the need to get trained on fire safety and emergency evacuation procedures?	☐ Very irrelevant ☐ Irrelevant ☐ Neutral ☐ Relevant ☐ Very relevant
How would you rate your current familiarity about fire safety and emergency evacuation procedures?	☐ Very unfamiliar ☐ Unfamiliar ☐ Neutral ☐ Familiar ☐ Very familiar
Which of the following types of fire safety or emergency evacuation training you received in <u>last year</u>?	☐ In-person lectures ☐ Slides & videos ☐ Hands-on ☐ Did not receive any such training ☐ If Other, please specify : __________
How frequently you participated in fire evacuation drill in <u>last year</u>?	☐ Never ☐ Once ☐ 2-3 times ☐ If Other, please specify:__________
How would you rate your comfort level in playing video / computer games?	☐ Very uncomfortable ☐ Uncomfortable ☐ Neutral ☐ Comfortable ☐ Very comfortable
How frequently do you play video / computer games?	☐ Never ☐ Yearly ☐ Monthly ☐ Weekly ☐ Daily

Knowledge Questionnaire

1. Which of the three elements are essential to start a fire?
   a. Oxygen
   b. Carbon dioxide
   c. Heat or source of energy
   d. Any combustible material
2. In case of fire emergency in a building, you should
   a. Use an elevator to quickly get out
   b. Look for nearest exit route
   c. If you are outside, quickly enter the building to grab your personal valuables
   d. Start reading instructions in order to use fire extinguisher
3. You should never fight a fire if
   a. There is a risk of toxic fumes or explosion
   b. You have no idea what is burning
   c. You do not know which fire extinguisher to use
   d. The fire is too small and not spreading
4. Fire extinguisher generally lasts
   a. Few seconds
   b. Few minutes
   c. About an hour
   d. Few hours
5. An ABC type fire extinguisher should be used against which of the following types of fires?
   a. A fire involving burning magnesium and plastic
   b. A fire generated when somebody poured water in a container that had sodium stored in kerosene
   c. A fire involving wood, gasoline and electric saw
6. What should be your course of action in following situation: You see fire coming out of the ceiling. There is a safe evacuation path behind you and visibility is good.
   a. Flee
   b. Fight
   c. Call a friend for opinion
   d. Wait for someone's instructions
7. You saw smoke coming out of an electric wiring. You want to alert others in building. What are the common locations of Fire pull station in Engineering 2 building?
   a. Next to elevator
   b. Next to restroom
   c. Next to water fountain
   d. Next to Exit doors

8. If you choose to fight a fire, where should you position yourself?
   a. As far away from the fire as possible to avoid getting hurt
   b. Next to a window so you can get out if your efforts to extinguish the fire are unsuccessful
   c. Six to eight feet from the fire, between the fire and your escape route
   d. As close to the fire as possible to ensure maximum efficiency of the extinguisher

Read the following case and answer questions 9 to 12.

When a student was using a microwave oven, it caught fire. She decided to fight fire and left the room in search of portable fire extinguisher. She returned after few minutes and in rush she tried to quickly read instructions on extinguisher and applied PASS (Pull, Aim, Squeeze, Sweep) method. The fire seemed to diminish but did not extinguish.

9. What is the most likely reason the fire did not extinguish?
   a. Student did not turn off the power supply
   b. Student applied steps of PASS method in incorrect order.
   c. Student did NOT quickly pour water on the fire from nearby tap
   d. It is not possible to extinguish fires involving electrical equipment with a portable fire extinguisher
10. Identify the CORRECT approach for extinguishing the fire in this case.
   a. Use Class B fire extinguisher
   b. Pour water from the nearby tap
   c. Use Class D fire extinguisher
   d. Use Class ABC fire extinguisher
11. Identify the CORRECT reason to fight the fire in this case?
   a. Since the fire started when student was using microwave oven, she felt obliged to extinguish it
   b. Student felt she could be a hero if she extinguishes the fire on her own
   c. Fire had just started and was small
   d. She did not want to bother everyone in the building by pulling the fire alarm
12. Instead of fighting fire if student had decided to flee, what should be her very FIRST step?
   a. Exit the building and reach safe place away from building
   b. Leave the room and close the door behind her to confine the fire
   c. Activate fire alarm system to notify occupants about fire
   d. Call 911 or university police by standing next to the fire

Fidelity Questionnaire

Please rate following on the scale of **1 to 5**

(**1** - Strongly Disagree, **2** - Disagree, **3**- Neutral, **4**- Agree, and **5** - Strongly Agree)

- Introductory exercise helped you to familiarize with the controls and navigation. ________
- It was easy to navigate in the virtual Engineering II building. ______
- The picture shown on the left from the training resembles that on the right from real life: _____

- Your familiarity with the escape routes and emergency exists of Engineering II building has increased after training. _________
- The demonstrated safety equipment shown on the left from the training resembles that on the right from real life. _______

- The elements depicting fire (smoke, flames, etc) resembled those that might be seen in real life. ______
- The scenario depicting fire alarm situation resembled what might feel like in real life. _______
- The simulation helped you to connect better with the potential real life scenarios. _________

Engagement Questionnaire

Please rate following on the scale of **1 to 5**.

(**1**-Strongly Disagree, **2**-Disagree, **3**-Neutral, **4**-Agree, **5**-Strongly Agree)

No	Description	Rating
1	The training material had significant new content that you were not aware of.	
2	The training experience was fun and enjoyable.	
3	The training seemed to have too much information and it failed to maintain your attention.	
4	It was difficult to concentrate on training material and you felt distracted.	
5	You are likely to remember most of the key concepts presented in training a month from now.	
6	Taking this training has modified your likely response to a real life fire / emergency evacuation situation.	
7	You would like to undergo same fire safety and evacuation training next year.	

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