A Development of Game-Based Learning in Virtual Reality for Fire Safety Training in Thailand

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***Abstract*— Fire incidents damaged both the economy and human life. In the past three decades, 59,387 fire incidents in Thailand approximately lost 40 billion baht and 2,076 deaths. Fire safety training methods are organized in a very limited number each year for many reasons such as training place or safety concern. We propose game-based learning for fire safety training using virtual reality technology. We create five learning lessons based on fire training contents and three playing stages (play, learn and test) that players can interact with. It behaves as a self-learning tool that can be used often and overcome the difficulty in organizing fire safety training. In addition, virtual technology simulates realistic computer graphic contents and rich interactive actions. Most importantly it offers a safe virtual environment; it extends the audience to a wide range of ages. Our game-based training is evaluated, and the result shows that fire safety knowledge is increased by 122% and 63% compared to the non-training and the traditional training respectively as well as users' satisfaction average score is exceeded 90%.**

Keywords—fire safety, game-based learning, virtual reality, serious game, training.

I. Introduction

Fire incident refers to danger arising from a fire that lacks supervision; covering broadly definition including small, large fire, or conflagration. According to the Department of Disaster Prevention and Mitigation, Ministry of Interior, Thailand, there were 59,387 fire situations in the past 3 decades (1989 – 2018) that approximately damaged the economy 40 billion baht, more importantly, 2,076 died and 5,413 injured [1], see Fig. 1. Both government and private agencies promote fire safety awareness and how-to-survive from the situation periodically to minimize the damage. The traditional training method involves workshop-based using mixed media such as an article or video-based content. It usually covers a definition of classes of fires, types of extinguishers and their operating procedures, fire situation demonstration, and first aid. Workshops are organized only a few times a year, which leads to a large number of audiences in each training, eventually, insufficient knowledge and difficulty to evaluate the training outcomes.

The Covid-19 pandemic complicates in organizing workshops. In this research, we propose an alternative fire safety training system using a game-based learning (GBL) strategy in a virtual environment or virtual reality (VR). Players learn the content while enjoying the gameplay and the immersive view suits the nature of contents by providing 360 degrees configurable environment and rich interactivity. A system offers a completed aspect of fire safety workshop: tutorial, training, and virtually practicing.

This paper is organized into five sections. The background and related to our work are discussed in the next section. The research methodology is explained in the third section. The fourth section explains the detail of the experiments and results. The Conclusion is discussed in the last section.

II. Background And Related Works

A. Game Base Learning

Game-based learning is generally a genre of game that defines a learning outcome [2]. Lessons are blended into the game allow players to learn by playing and practicing on their own; have fun while learning. GBL attracts players by

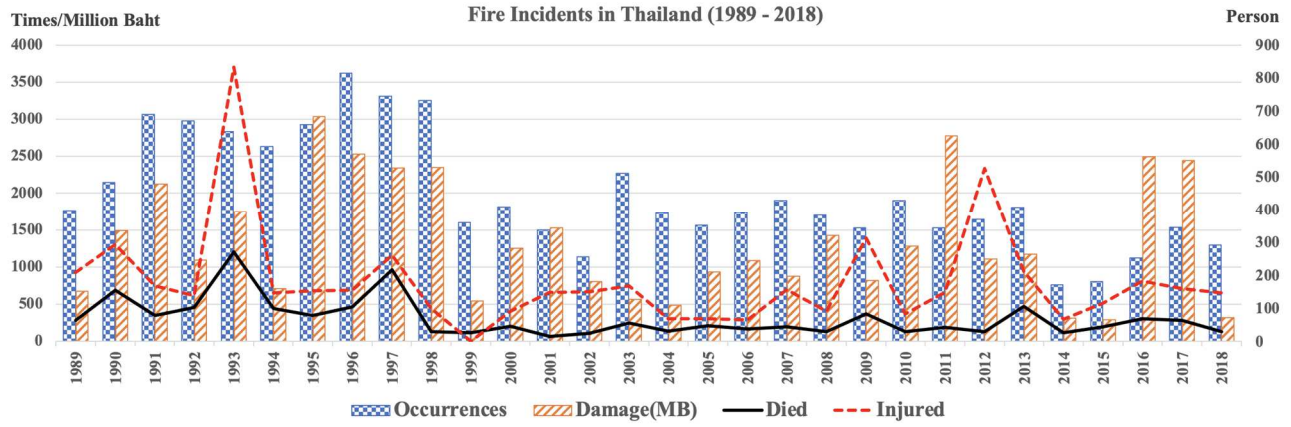

Fig. 1. Fire incidents in Thailand in 1989 - 2018 and its statistic: number of casualties, injured, the economic damage.

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simulating situations, challenging and encouraging them to form self-taught learning. In addition, it motivates the players to overcome difficult tasks; splitting the subject into several small pieces and delivering in the form of gameplay eases the learning curve. However, designing a good GBL is not an easy task. GBL designers need to design the game structure carefully by considering and validating the contents to match its learning outcomes as well as entertaining.

GBL continuously gains popularity, one of its reasons is technological advancement, therefore, the game becomes more interesting in terms of visualization and interaction. It benefits players learning ability (if carefully designed) and influences four positive impacts: cognitive, motivational, emotional, and social (multiplayer) [3]. Plass et al. [2] have reasoned the elements of why the game is an effective learning environment as follows: motivation, player engagement, adaptation, and graceful failure, details as follows.

Motivation is an empirical characteristic of games as the entertainment media. Its rewards are represented in many forms such as points, stars, trophies, or levels. These attributes are often used for learning motivation.

Player engagement is used interchangeably with an activity that players communicate with the game. The digital game provides many ways that help players with the most ability to interact with and invite them to engage.

Adaptation is the capability of the game that engages each player in a way that reflects his or her specific circumstance. Game measures all the variables, e.g., prior knowledge, and, therefore, offer the appropriate response to the players.

Graceful failure is often required, or even necessary, in the learning process. The capacity to fail gracefully is associated with previous elements, such as motivation, player engagement, and adaptation. It challenges players to try new things and exploring towards the game objectives.

B. Virtual Reality Technology

Virtual reality is a technology that simulates a real-world environment with 3D computer graphics. It allows users to interact by using a set of wearable devices that consist of input (e.g., hands tracking devices), processing (e.g., computer), and display units (head mount display: HMD).

VR technology is utilized in many applications, its popularity for entertainment and education/training purposes. Not only an immersive graphical but also the safety training environment.

C. Motion Sickness in Virtual Reality

Despite the compelling experience from wearing an HMD device, one of the most common side-effects is a motion sickness symptom; this typically refers to dizziness, vomiting, and nauseated feeling. Recent works have exposed multiple factors that cause this symptom such as gender, VR environment genre (shitting from pleasant to horror), posture, or graphical properties [4].

Moving in a virtual environment has two general types: steering locomotion and teleporting. Steering locomotion is a type of movement where users continuously initiate their moving towards the destination using the input controllers [5]. On the other hand, teleporting is where users determine the destination and are intermediately translated to that location by pressing a button [6].

Based on human sensory conflict theories, one motion sickness severity is predicted to be lower with teleporting technique [7]. Therefore, in this work, we implement a teleporting technique that translates user position to each destination; users' posture is a sit position while playing. Note that one of a question in an experienced assessment (see section IV.) of our work is whether or not user experiences motion sickness while playing.

D. Traditional and Virtual Reality in Fire Safety Training

Traditional fire safety training uses one of these methods: articles and video-based content, or demonstration workshops. These methods are considered as a passive procedure; trainees read, listen, or watch the contents and self-learning without or hardly provide interactive activities. One common factor is that it lacks instant knowledge assessment and feedback; there are many reasons such as one-way communication (in case of article or video-based), a large number of trainees in the workshop, or safety concern. Eventually, effective evaluation is difficult to perform.

In contrast to traditional methods, one of the most important features of training in virtual reality is its safety and rich interactive environment [8], [9]. It allows teaching a dangerous subject with more realism and safe while gaining knowledge with less effort compared to the traditional teaching process [10] and cost-effective solution [11].

Fire safety training is fit into a training category that suitable to exploit fire safety training in a virtual environment. The most vulnerable habitat during a fire incident is children [8], therefore, using safety space training expands the age of the audience from child to adult to be attended. In addition, virtual reality training increases the effective result of the trainee and maintained self-efficacy even 3-4 weeks after completed the training [12].

Benefiting VR training for human behavior, including fire safety, has been reported in numerous disaster and emergency situations [13]–[15]. Recently, Saghafian et al. introduce fire extinguisher training in virtual reality [16]. In this work, a VR tracking device is installed with a real extinguisher so that player can realistically feel the device while observing its result in VR view. Training focuses on fire extinguisher operating procedures to put out the fire. Lovreglio et al. propose a comparison of the effectiveness between traditional and virtual reality training environments [12]. Similarly, it focuses on operating fire extinguisher operating procedures.

Unfortunately, to our knowledge, there is no system that covers all aspects: educating knowledge of fire, extinguishers, and their operating procedures as well as the emergency contact numbers and first aid. We propose a system that combines all pieces together; it allows trainees to get educate and practice all training aspects. The comparison training features of our system with the traditional and available product [17] in the market is displayed in Table I. It is obvious that our training offers two systems combined except practicing with a real extinguisher.

III. METHODOLOGY

In this section, we describe the methodology and technology that are used to develop the system. There are 3 main parts: contents, gameplay and system development.

TABLE I. TRAINING FEATURES COMPARISON

Training Features	Traditional Fire Safety Training	Fire Safety Lab VR [13]	Our Proposed
Training Time Independent	✗	✓	✓
Classes of Fire	✓	✗	✓
Types of Extinguishers	✓	✓	✓
Emergency Contact Numbers	✓	✗	✓
Operating Extinguisher Procedure	✓	✓	✓
First Aid	✓	✗	✓
Training Assessment	✗	✗	✓
Safety Environment	✗	✓	✓
Practice with Real Equipment	✓	✗	✗

A. *Fire Safety Contents*

Based on fire safety info from the Fire and Rescue Department, we split training contents into five lessons.

1. Classes of fire – there are five classes of fire, based on firing cause materials, see Table II.
2. Types of extinguishers – there are six types of extinguisher, based on the substance used. Use cases of each type are displayed in Table II.
3. Emergency contact numbers – there are five emergency phone numbers that relate to the fire situation workforces.
4. Operating extinguisher procedures: the common procedure to operate are pull, aim, squeeze, and sweep (PASS).
5. First aid – ability to handle the first aid in the event of fire-affected.

Choosing the correct type of extinguisher for any class of fire is crucial because some extinguisher substance stop multiple types of fire while choosing the wrong one cause the opposite or even aggravate the fire situation. Table II summarizes the options of extinguishers versus the class of fires.

B. *Game Design and Game Based Learning*

Gameplay is designed based on the last sub-section contents. There are 3 main stages: learning, play, and test (LPT), these stages are presented to players sequentially.

Learning stage comprises of 4 tutorials: the 1st combines a lesson 1 and 2 which is used together, the 2nd explains the detail of lesson 3 while the 3rd and 4th provide lessons 4 and 5 respectively. All tutorials are video-based content.

Play stage is a simulated situation that allows players to practice the content interactively. There are 2 situations: the 1st simulates the knowledge trained from tutorials 1 and 2 while the 2nd simulates the tutorial 3 and 4. The play sequences are controlled by a game system; the 1st play is presented to players once they complete the first 2 tutorials while the 2nd is presented after players complete the last 2 tutorials.

Test stage is a fire safety knowledge assessment, we use the pre/post-test questionnaire method to ask player before and after playing a game. There are two sets of questions: knowledge-based and user experience based.

GBL framework explicitly defines the learning objective of each tutorial. Thus, the 4 tutorial objectives are understanding classes of fire and types of extinguishers, knowing how to contact the fire safety agencies, ability to operate extinguishers, and understanding how to do a first-aid procedure respectively.

TABLE II. FIRES AND EXTINGUISHERS CATEGORIES

		Classes of Fire				
		Ordinary Combustibles (A)	Flammable Liquids (B)	Electrical Equipment (C)	Combustible Metals (D)	Combustible Cooking (K)
Types of Extinguisher	Dry Chemical	✓	✓	✓	✗	✗
	Foam	✓	✓	✗	✗	✗
	Carbon Dioxide	✗	✓	✓	✗	✗
	Halotron	✓	✓	✓	✗	✗
	Water Gas	✓	✗	✗	✗	✗
	FireAde 2000	✓	✓	✓	✓	✓

Fig. 2 shows a game-level design. There are 2 areas: VR tutorial area and learning area. Fig. 2(a) is the preparation stage that helps players to understand how to use a VR device and navigate inside a virtual environment. Players learn how to teleport from one place to another for navigating around the virtual environment as well as using controller device to learn a skill of how to pick or release an object which is required in the learning area. Fig. 2(b) is where learning and playing are taken place; it consists of 5 positions that are randomly simulated fire incidents. Complete all tutorials and plays require approximately 20 to 25 minutes depends on each player. Learning stages are not limited by time (players can re-try as needed) while the test stage time is limited (players must pass the challenge within the time limit).

Note that the virtual environment in this game is designed as a medium-size indoor area with simple decoration to give players a pleasant feeling while playing. Teleporting in a small area reduces the conflict between immediate movement in a virtual space and human sensory to minimize motion sickness.

C. *System Design and Development*

Fig. 3 describes a game system and flowchart. We develop a system using Unreal Engine 4 (UE4) and implement it on the Oculus Quest (VR device) platform. Game uses a first-person perspective which enhances players' view as they are in the middle of the situation.

Input and output of a system are Oculus Quest device – it is a standalone device which does not require connecting to a computer, therefore, the player has a 6 degree of freedom while playing. The input is a set of sensor devices that receive actions from players; these include pressing buttons, motion sensors. The output is delivered through head mount display (HMD) which offer 110 degrees field of view.

For an immersive visualization, we implement the high polygon assets while maintaining the high framerate. Two important animation assets in our game are fire and extinguisher which are used interactively when players learn how to use the extinguisher procedure.

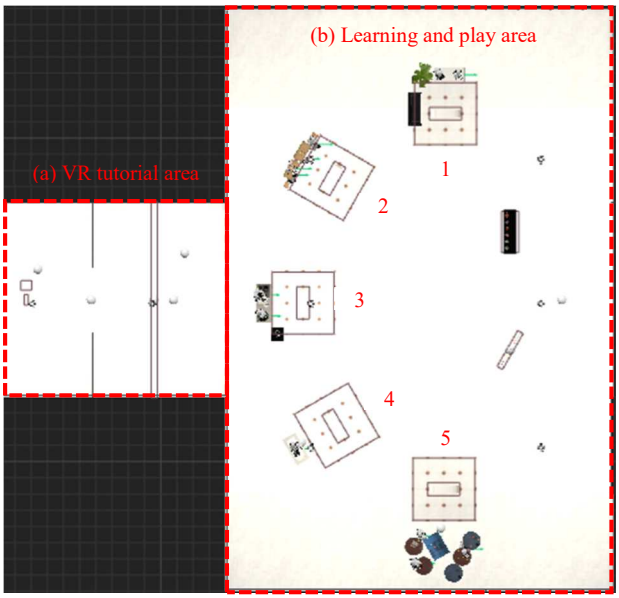


Fig. 2. Game level (a) VR tutorial stage is the first scene that player learn how to navigate in virtual environment with VR controller (b) learning and play stages, the labels 1-5 are the locations that game randomly simulates different types of fire for practicing.

IV. Experiment and Result

A. *Experiment*

We design the experiment on volunteers who have not trained in fire safety. There are 11 volunteers (who never attend an official fire training course) of an average of 21 years of age; the gender is equally balanced between male and female. Volunteers are split into two groups for evaluating purposes: our game-based training and traditional training method. The number of volunteers in each group is 6 and 5 persons respectively. Note that, there are many factors such as gender or cultural differences that probably affect the learning outcome when adopting GBL as a learning medium. The studies in [18], [19] show that males and females perform the comparable result, however, males tend to slightly better handle new learning tools or anxiety than females.

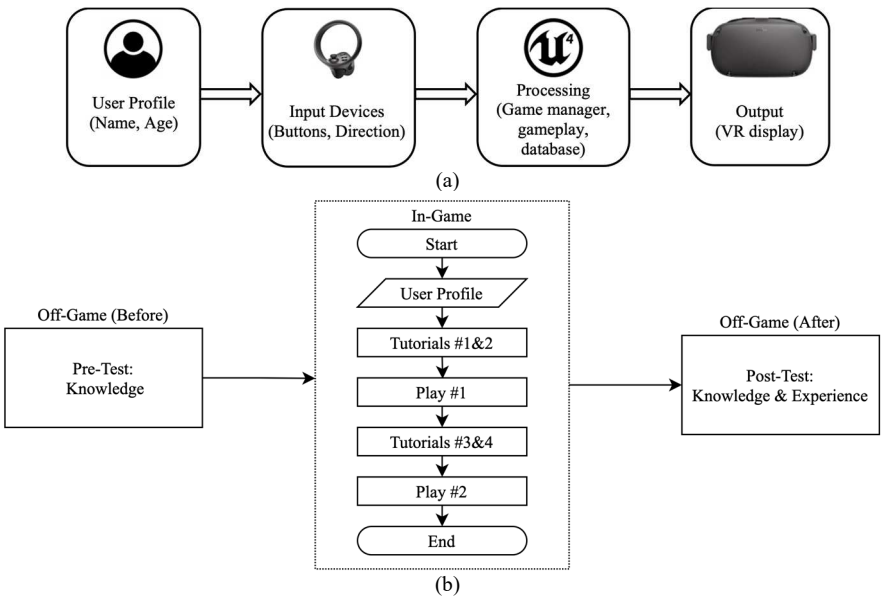


Fig. 3. Game system overview: (a) development software and device (b) game flow chart show the gameplay sequences where the pre/post-test are performed outside the system.

TABLE III. KNOWLEDGE EVALUATION RESULT

Knowledge Test (Total 10 Questions)	Average Score		
	Pre-Test (11 Persons)	Post-Test	
		Article Based (5 Persons)	VR Based (6 Persons)
Emergency contact (2 questions)	22.73%	30.00%	75.00%
Classes of fires (3 questions)	45.45%	60.00%	100.00%
Types of extinguisher (2 questions)	18.18%	40.00%	66.67%
Operating extinguisher (1 questions)	45.45%	60.00%	83.33%
First Aid (2 questions)	59.09%	70.00%	91.67%
Average Score (10 questions)	**38.20%**	**52.00%**	**85.00%**

Therefore, we are safe to assume that the gender difference does not affect by this experiment.

In the first group, all volunteers are required to complete the game and performed the test. Playing game is independent and each player has no interference from/to others. Similarly, the second group learns the identical contents through provided articles. Completing the game takes approximately 20 – 25 minutes, depends on each player's performance.

Note that each volunteer performs a knowledge pre-test which covers all lessons, details refer to section III. Then, training with our proposed game or an article-based. Lastly, performing a knowledge post-test and user experience questions. The perspective questions and results are displayed in Tables III and IV.

B. Result

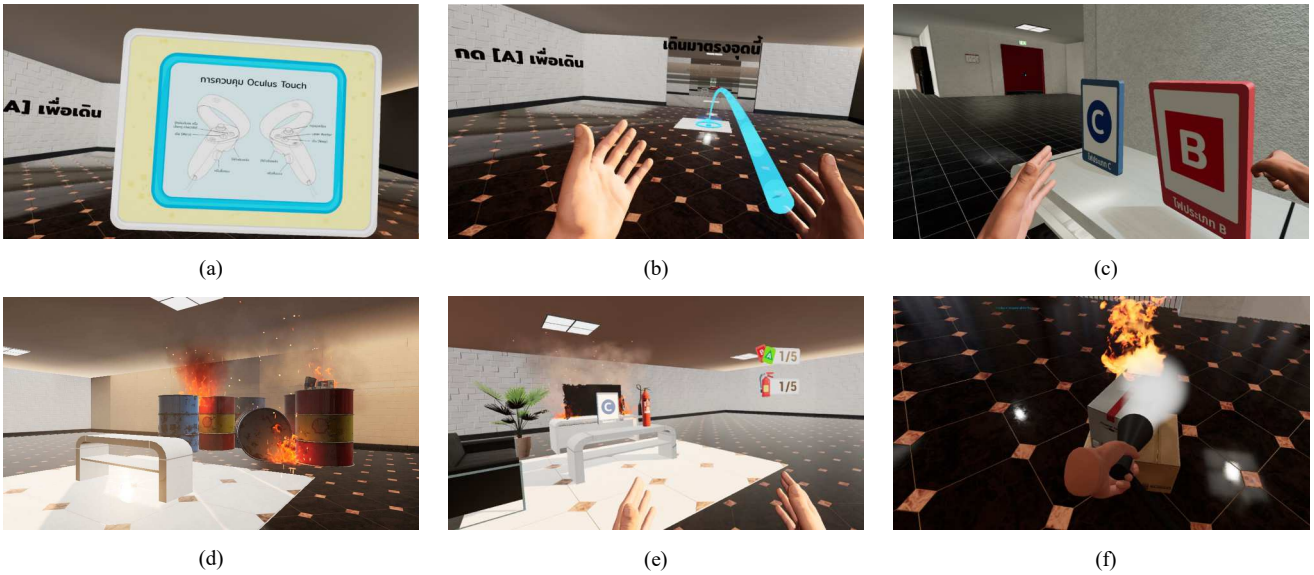
Fire safety knowledge evaluates how much knowledge players gain while user' experience evaluates how much players like a game. Fig. 4 captures several actions from our game. The following summarizes the results.

1. Knowledge – the average score of pre-test and post-test of an article-based, and our game-based are 3.82/10, 5.2/10, and 8.5/10 respectively.
2. Users' experiences – most of the players, over 90%, like the gameplay, artistic and recommend this training game to others. Note that the motion sickness score is approximately 50% while the recommendation game to others score is approximately over 90%.

Details of knowledge evaluation based on 5 contents are explained in Table III. The comparison score between pre/post-test of each lesson is calculated by the total number of testers who answer correctly. Details of users' experience evaluation are explained in Table IV.

TABLE IV. USERS' EXPERIENCE EVALUATION RESULT

Users' Experience Opinion (Total 7 Questions)	Ave Score (5 points)	Description
1) Game artistic	4.83	Higher is better
2) Player skills to complete the game	3.17	Lower is better
3) Content narrative and sound quality	4.83	Higher is better
4) Difficulty level of VR usage in game	3.17	Lower is better
5) Gameplay procedure (difficult or easy to understand)	4.50	Higher is easier
6) Recommendation game to others	4.67	Higher is better
7) Feeling motion sickness while playing	2.60	Lower is better



(a) (b) (c)

(d) (e) (f)

Fig. 4. Game in actions: (a)-(b) preparation stage teaches how to use VR device and navigating in the game, (c)-(e) matching classes of fire with types of extinguishers, and (f) practicing extinguishers following pull, aim, squeeze, and sweep procedure.

V. Conclusion and Future Work

We proposed fire safety training game-based learning using VR technology; it covered all key components from emergency contact numbers, classes of fire, types of extinguishers and its operating procedures as well as a first-aid procedure. The main contribution is we demonstrate how difficult and dangerous tasks such as fire safety training can be done for all types of audiences by employing the existing technologies such as VR and game-based learning strategy. It showed that both the knowledge and experience from our system are high. The knowledge score is increased by 122% and 63% compare to the non-training and the traditional training respectively, and over 90% of users recommended it to others while the motion sickness level is moderate.

The game provided immersive content, rich actions, and instance practicing. Users instantly got feedback which helps them analyze and improve their knowledge. In addition, it offered dangerous-free training because the system simulates fire situations in a virtual environment.

However, there are several possibilities to improve our system. For examples, the in-game pre/post-test feature or multiplayer training networks which drive game-based learning mechanism; play with a team to collaborative or competitive and to complete the game objective. In addition, fire evacuation training also is possibly extended to our game.

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