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Development of fire safety behavioral skills via virtual reality

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ABSTRACT

In recent years, virtual reality has become prevalent in many educational settings. In this study, virtual reality-based behavioral skills training (VR-BST) approach is proposed to teach basic behavioral skills for fire safety. A virtual reality-based environment was designed and implemented in the context of the design-based research. A group of ten primary school students received a basic fire safety training package through this environment and in situ training was implemented when needed. The results indicated that students' fire safety behavioral skills significantly improved with the use of virtual reality based training and the majority of the students could transfer their behavioral skills to real environments. The way of modelling the behaviors in this study and integrating in situ training into the learning environment positively contributed to the development of behavioral skills. The study concludes with suggestions for practitioners and researchers in the field of virtual reality for behavioral skills training.

1. Introduction

Children face a variety of life-threatening situations in their daily lives. Drowning, burning, firearms, and poisoning are among the leading causes of death due to injury to children between 5 and 10 years of age (Centers for Disease Control and Prevention, 2011). Thus, behaviors exhibited by children in such situations are important for their personal safety. At this point, generally, two methods are employed to prevent injuries or deaths (Vanselow, 2013). One short term beneficial method is the environmental modification in which children are kept under control by parents and security of children is provided by keeping harmful objects in places where children cannot reach. Vanselow (2013) argues that with this method, children may be able to provide personal security but their adaption of related skills to different dangerous situations is not developed sufficiently. In this sense, another way is suggested to train how to behave in various dangerous situations. However, some of the researchers have criticized the limitations in the training processes, the technology used in the behavioral skills training sessions in that they are not sufficient for developing correct behavioral skills in case of danger (Beck & Miltenberger, 2009; Himle, Miltenberger, Gatheridge, & Flessner, 2004). Even though there is some research directed on developing behavioral skills, a need exists for more innovative approaches for teaching safe behavioral skills to children (Kelso, Miltenberger, Waters, Egemo-Helm, & Bagne, 2007; Miltenberger et al., 2009). In this context, effective learning environments in which children can practice by encountering dangerous situations should be designed (Vanselow, 2013). In this work, the authors designed and implemented a virtual reality-based learning environment for training process of behavioral skills for fire safety.

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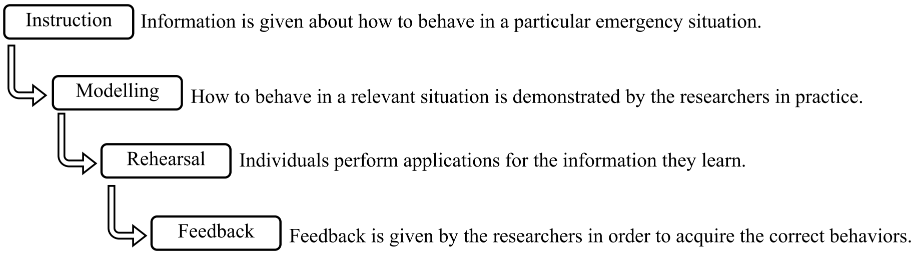

Fig. 1. Behavioral skills training model.

1.1. Behavioral skills training

Behavioral skills training (BST) is used to teach a variety of behavioral skills for various situations (Himle & Miltenberger, 2004; Stewart, Carr, & LeBlanc, 2007). In addition, BST is one of the effective methods used to acquire behaviors that should be exhibited in case of emergency (Mazo, 2014). It is also used for teaching personal safety skills to individuals from various age groups and skill levels for abduction, firearm safety, sexual harassment, wild animal injuries, and fire safety (Houvouras & Harvey, 2014; Mazo, 2014; Rosales, Stone, & Rehfeldt, 2009). The BST suggests students to be active in learning environments and proposes a structure of instruction, modeling, rehearsal, and feedback during the teaching of behavioral skills (Himle & Miltenberger, 2004; Stewart et al., 2007). The structure of the model is summarized in Fig. 1.

In BST-based training, participants exhibit behaviors naturally in realistic environments. Feedback through in situ training (IST) is provided and in situ assessment (ISA) is implemented to enhance participants' behavioral skills and also to support their skills to be permanent (Beck & Miltenberger, 2009; Dancho, Thompson, & Rhoades, 2008; Himle, Miltenberger, Flessner, & Gatheridge, 2004; Jostad, Miltenberger, Kelso, & Knudson, 2008; Miltenberger et al., 2009). Some studies documented that using BST is sometimes not adequate for developing behavioral skills of young children and many of them cannot avoid dangerous situations. Moreover, some researchers reported that students may interact with a dangerous situation without asking any help from adults (Dancho et al., 2008; Himle et al., 2004; Johnson et al., 2006). In such cases, the BST is supported by the IST. During IST, Participants are observed by an adult, teacher, trainer or expert and when the participants exhibit wrong behaviors causing risks, the trainer comes near the participants and directs them to display correct behavior (Vanselow & Hanley, 2014). These directions are maintained until the participants exhibit correct behaviors. Corrective feedback is given to direct correct behavior to be exhibited in case of a dangerous situation. This attempt is made until the exhibition of the behavior in an expected level. In this way, it is possible to reinforce the behavior, to generalize it to similar situations and to ensure its sustainability in daily life (Gatheridge et al., 2004; Johnson et al., 2006). However, some studies reported that it is difficult to implement the BST and IST with a large number of student groups (Himle & Miltenberger, 2004; Jostad & Miltenberger, 2004). Vanselow (2013) also noted that ISA can be time consuming for training young students. At this point, verbal responses can be implemented to overcome limitations instead of behavioral responses.

During the BST, individuals interact more actively in simulated environments and encounter realistic experiences of dangerous situations (Himle & Miltenberger, 2004). In this respect, it is important to be close to reality in the environments created in BST-based training. However, creating realistic learning environments for training about the dangerous situations such as earthquake, flood, storm, fire, etc. is so difficult. Hence, BST is reshaped as computerized behavioral skills training (C-BST) approach for such dangerous situations. In this approach, instruction, modeling, rehearsal, and feedback are performed with various visuals, videos and interactive games via computer environment. Instead of typical BST implementations given by a tutor directly, C-BST is found beneficial and time saving for BST interventions to a wider range of participants (Vanselow, 2013). C-BST also allows the tutor to take individual characteristics of the participants into consideration in the design process. It is also useful for verbal or performance-based evaluations. On the other hand, lack of the sense of reality causes some disadvantages in these environments (Park et al., 2011). In this sense, considering the potentials of virtual learning environments, participants can feel more realistic and they can try and error in comfortable manner (Seckinger-Bancroft, 2010). Thus, this study uses virtual reality embedded in the C-BST approach to create more realistic environments for modeling behavioral applications.

1.2. Virtual reality

Virtual reality is the presentation of a real-world situation in a computer-generated 3D simulation. Users interact with the simulated environment through special wearable devices (Ausburn & Ausburn, 2004; Chuah, Chen, & Teh, 2008; Freina & Ott, 2015; Negut, Matu, Sava, & David, 2016; Serrano, Baños, & Botella, 2016). In these systems, the positional data of the head movements of the users are transferred to the avatars through the head-mounted displays (HMDs), so that the avatars are directed simultaneously.

As virtual reality environments become closer to reality, the perceived presence and participation of learners increases (Passing, David, & Eshel-Kedmi, 2016). In this case, learners feel as if they were the components of the environment. This is addressed in the immersiveness feature of virtual reality. Researchers point out that successful learning outcomes are noticed through using HMDs in the immersive environments in the training of such skills as social skills (Park et al., 2011), emotional and social adaptation skills (Ip et al., 2018), surgical skills (Aggarwal et al., 2007; Kühnapfel, Çakmak, & Maaß, 2000; Larsen et al., 2009), and security skills for various dangerous situations (Grabowski & Jankowski, 2015).

1.3. Virtual reality-based training

Initially, the use of virtual reality in learning environments was limited due to the simulator-based and high cost of the devices. Today, with the integration of immersive virtual reality technologies in learning environments like Second Life, Active Worlds, learning activities can be realized with more interactive, real and safe. Researchers emphasize that when virtual reality is used for educational purposes, learning becomes more fun and intriguing within the components of interaction, immersion, and involvement in risky situations which are impossible to practice and cannot be experienced in real life (Cha, Han, Lee, & Choi, 2012; Freina & Ott, 2015; Smith & Ericson, 2009).

Studies have put forth that using virtual reality in learning environments by providing high-level interactive experiences for learners supports peer-collaborative learning (Chittaro & Ranon, 2007; Huang, Rauch, & Liaw, 2010; Lau & Lee, 2015), develops problem-solving skills, helps learners explore new concepts by offering rich teaching contents (Huang et al., 2010; Leite, Svinicki, & Shi, 2010), increases learner motivation and engagement (Freina & Ott, 2015; Limniou, Roberts, & Papadopoulos, 2008; Ott & Tavella, 2009), enables learners to gain knowledge with less effort than traditional teaching process (Chittaro & Ranon, 2007), and makes the dangerous teaching process more realistic and safe (Freina & Ott, 2015; Johnson & Levine, 2008).

1.4. Virtual reality in fire safety training

During a fire, children are often vulnerable and await help from an adult without deciding how to behave. In this regard, Centers for Disease Control and Prevention (2011) documented that the causes of death related to injuries are listed among the top 10 causes of fires in the age range of 5–9 year children. Therefore, it is important to increase the knowledge, skills, and experiences of young children in terms of fire safety and fire protection independent of adults.

At this point, virtual reality has an important potential for fire safety training through serious game-based training and simulators (Backlund, Engstrom, Hammar, Johannesson, & Lebram, 2007), offering self-learning methods (Chittaro & Ranon, 2009), and experiencing realistic experiences (Smith & Ericson, 2009). In prior studies, the virtual reality-based learning environments for fire safety were generally non-immersive and they were often used to train adults and professionals (Cha et al., 2012; Smith & Ericson, 2009; Xu, Lu, Guan, Chen, & Ren, 2014). In particular, since behavioral skills are taught when fire safety training is given to children, more immersive designs are needed and some new models to build the virtual reality-based learning environments should be suggested for fire safety training. With this in mind, this study examines the effectiveness of virtual reality-based designs in training for children in terms of fire safety skills. BST is taken as the basis for the designs and applications, and the virtual reality-based behavioral skills training (VR-BST) approach is proposed. Since the fire has a large area, this study is focused on the residential fires that children are more likely to encounter. During the training sessions, IST and ISA are implemented and their contributions to the fire safety skills are also examined. Thus, current study seeks to answer the following questions:

1. To what extend does virtual reality-based behavioral skills training impact the development of fire safety behavioral skills?
2. How do learners transfer behavioral skills to real-life conditions with virtual reality-based behavioral skills training?

2. Method

Seeking to increase the impact, transfer, and translation of education research into improved practice, this research was carried out as a design-based research. In addition, it stresses the need for theory building and the development of design principles that guide, inform, and improve both practice and research in educational contexts (Anderson & Shattuck, 2012). Design-based research provides being situated in a real educational context and focusing on the design and testing of significant intervention. The process of design-based research involves a cycle among analysis, design, and evaluation (McKenney, Nieveen, & Van den Akker, 2006). The analysis stage provides guidelines for the design, aiming at closing gaps between theory and practice. The design stage is a dynamic, systematic prototyping approach that involves modeling, testing, evaluating and revising to optimize the practice. Lastly, the whole process is evaluated during the evaluation phase. Considering these phases, in this study; it was determined that virtual reality can be used for fire safety training in the framework of DBE approach. In the design phase, the VR-FST environment was developed based on the model proposed by Yusoff, Zulkifli, and Mohamed (2011). This model includes awareness of problem, suggestion, development, evaluation, and conclusion sub-stages. In this phase, VR-FST environment was developed by the researchers and evaluated with a pilot study. Finally, the usability of proposed VR-BST approach for behavioral skills training was tested with 10 children.

2.1. Conceptual framework

The features that enhance the interaction, participation, and sense of presence presented by virtual reality technology are integrated with the methods suggested by VR-BST model. The relationship between the concepts and models underlying VR-BST is shown in Fig. 2.

2.2. Participants

Participants of the study consisted of 10 children aged 9–11 years. The experiences in virtual reality and fire were taken as two main issues in terms of the possible factors influencing the success of the design and implementation. Thus, participants were selected

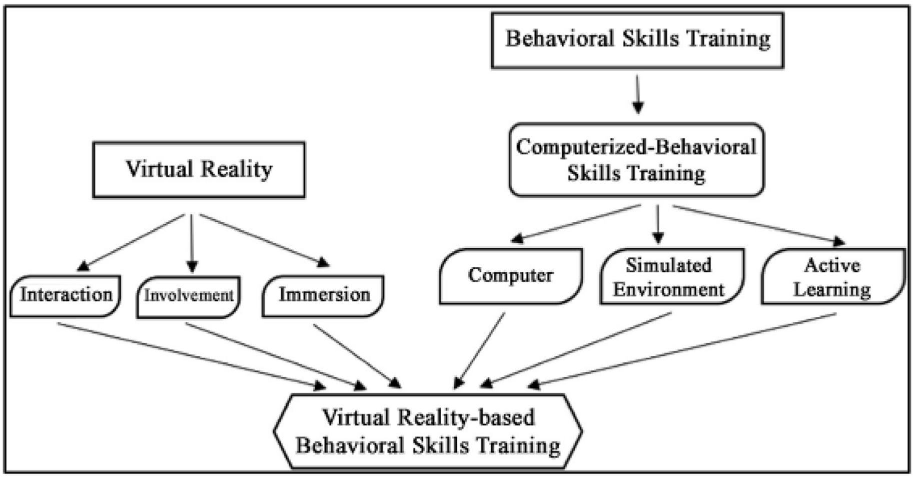

Fig. 2. VR-based behavioral skills training model (VR-BST).

regarding their experiences of the computer gaming, fire encounter, participation in a fire drill, and a fire safety training. Due to the young age of the participants, family consent was taken to include children in the study. Participants' characteristics are presented in Table 1.

2.3. Environment

The design method proposed by Yusoff et al. (2011) was used in the design process of virtual reality-based fire safety training (VR-FST). VR-FST was created by integrating virtual reality technology (HMDs) in a 3D and multi-user virtual environment (Second Life). Participants were represented in the VR-FST environment through avatars. The participants observed the environment from the avatar's point of view through the HMD, they navigated in the environment using the joystick and explored the VR-FST environment auditory using headphones. A sample view from thr VR-FST environment is shown in Fig. 3.

A considerable effort is invested for the tasks and the design to provide a realistic environment in VR-FST. By doing so, we aimed to increase participation with the realistic designs of the objects and increase feeling of presence in the activities. Thus, participants can experience active learning in a simulated environment using avatars.

2.3.1. Pilot study for testing the environment

The VR-FST environment was tested via a pilot study conducted with 6 children aged 9–11 years. The fire safety training was provided for residential fires by a firefighter avatar in the VR-FST environment. After the training, several tasks such as exploring and finding an object hidden in a house were implemented as scenarios on VR-FST. The participants were requested to complete these tasks using HMD and joystick. While they were acting to achieve the tasks, fire and smoke effects and their behaviors were included to the VR-FST environment. The perceptions about the realistic level of the environment were evaluated according via the questionnaire data. The process in the training is summarized in Fig. 4.

At the end of the pilot study, presence questionnaire (PQ) developed by Witmer, Jerome, and Singer (2005) was applied to determine the level of presence felt by the VR-FST environment. The participants' presence scores are shown in Table 2.

Table 2 indicates that all of the participants have a high level of presence in the VR-FST environment and perceived the environment as sufficiently realistic.

Table 1
Demographic information of the participants.

Participants	Gender	Age	Computer Gaming Experience	Fire Encounter Condition	Participation in Fire Drill	Fire Safety Training Status
P1	Female	11	5 years and above	No	No	No
P2	Male	10	5 years and above	Yes	No	No
P3	Female	9	3–4 years	Yes	Yes	No
P4	Female	10	1–2 years	No	No	No
P5	Female	11	1–2 years	No	No	No
P6	Male	9	1–2 years	No	Yes	Yes
P7	Male	10	3–4 years	No	No	No
P8	Female	11	5 years and above	No	No	Yes
P9	Male	11	5 years and above	No	Yes	No
P10	Female	10	1–2 years	No	No	No

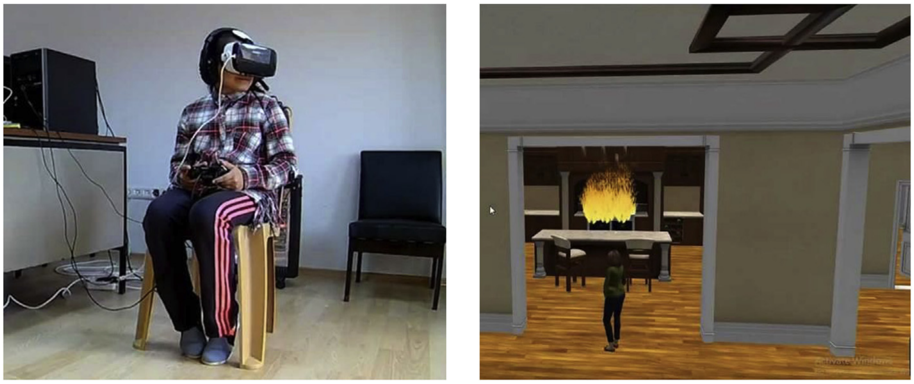

Fig. 3. The interactions between the Mentors and Teachers.

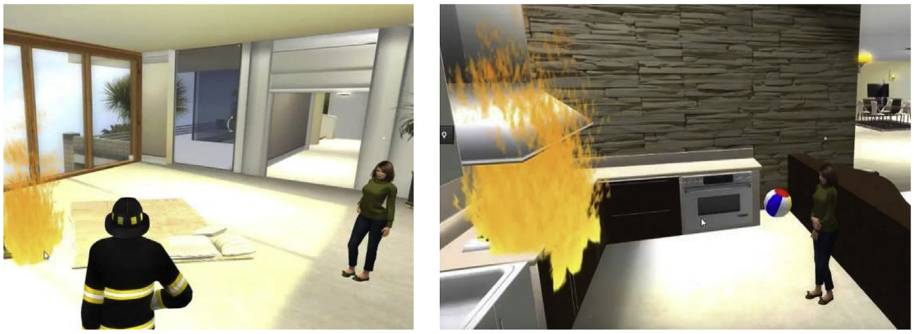

Fig. 4. A view from training and implementations.

Table 2
PQ scores in the pilot study.

Participants	Involvement	Adaptation/Immersion	Sensory Fidelity	Interaction	Interface Quality	Mean
P1	3.11	3.71	3.40	3.20	3	3.31
P2	4.44	4.43	4.60	4.20	4.67	4.45
P3	4.67	4.71	4.80	4.80	5.00	4.76
P4	4.22	4.14	4.00	3.40	4.33	4.03
P5	4.00	4.86	5.00	4.20	4.33	4.45
P6	4.56	4.71	3.80	5.00	4.33	4.52

2.4. Data collection tools

The research data were obtained from the observations through basic fire safety skills observation form, semi-structured interviews and the PQ.

2.4.1. Basic fire safety skills observation form

The basic fire safety skills observation form was developed by the researchers in order to evaluate the changes in the participants' behavioral skills. The social validation of the behaviors method (Jones, Kazdin, & Haney, 1981) was used in constructing the observation form. First, national and international regulations such as Turkey's Regulation on Fire Protection (BYKHY) and National Fire Protection Association (NFPA) were used to determine basic behaviors for keeping safe in residential fires. In addition, behavioral patterns that people show against fire (Demirel & Arı, 2009) and fire safety principles published by the leading fire departments in Turkey were used to determine the basic skills in residential fires for 10-12 year-old children. Second, after the reviews of 50 firefighters by scoring the behaviors due to their importance, 5 basic behaviors were determined crucial for the residential fires. Third, regarding the understandability of the form; 30 students in the ages of 10–12 filled the form and reviewed it. The final form of basic fire safety skills is shown in Table 3.

2.4.2. Presence questionnaire (PQ)

Presence questionnaire was used to determine the level of the presence felt by participants during the training. The original form of the questionnaire was developed by Witmer et al. (2005) and adapted to Turkish by the authors. In the adoption process;

Table 3
Basic fire safety skills.

Score	Behavior	Definition
0	Interact with fire	Examine and attempting to extinguish the fire
1	Stay near fire	Do not leave the fire area
2	Tell an adult	Notify adults with a loud noise after realizing the fire and stay in the fire area
3	Get away	Leave the fire area within 30 s
4	Get away and tell	Notify the adults or the firefighter department after leaving the building

considering the age of the participants, the adapted scale is converted from 7-point to 5-point likert type. In this sense, Dawes (2008) addressed that the scales provide similar results when applied in 7-point or 5-point likert-type. The adapted scale was applied to 431 students aged 9 to 14 and exploratory (EFA) and confirmatory factor analyses (CFA) were done. As a result of the EFA, it was determined that the 5 factors explained 41.197% of the total variance. The results of CFA indicate that; the model fit indices $\chi 2/df = 1.55$, RMSEA = 0.036, SRMR = 0.051, GFI = 0.92, AGFI = 0.90, NNFI = 0.96, and CFI = 0.97 were determined. The Cronbach Alpha (α) reliability coefficient was found as 0.844.

2.4.3. Interviews

Interviews were used to deeply understand and explain the reasons for the behavioral skills that students exhibited with the influence of the VR-FST. The experiences of participants regarding the sense of reality in the VR-FST and the benefits from the environment were asked to the participants. Interviews lasted approximately 20–25 min and they were recorded with audio recorders.

2.5. Procedure

The study consists of the development and training phases. VR-FST has various activities organized through basic fire safety skills. Prior to design, basic behavioral skills were modeled as behaviors. The training was conducted individually with 10 volunteers. The implementation is carried out in different time periods, is summarized in Fig. 5.

One of the scenarios in the designs used during the training process is shown in Fig. 6.

Before taking the students in the VR-FST environment, they were informed about how they would use the environment. In the scenarios, participants were exposed to predetermined fire situations. The participants performed the tasks with their avatars and they navigated inside the rooms of a residence in the VR-FST. During the training, behavioral skills training for basic fire safety was provided through the VR-FST environment. The instruction, modeling, rehearsal, and feedback steps of the BST were conducted using avatars on the VR-FST environment. Participants were provided to repeat the rehearsal phase five times.

During the IST + ISA (VR-FST) phase, the participants were taken to different residences on the VR-FST environment and exposed in fire situations. Behaviors exhibited by participants on VR-FST for their respective fire situations were observed. In the ISA phase, when the participants were unable to fully demonstrate the correct behavior in IST, feedback was provided to direct them to show appropriate behavior. The feedback process continued until the participants could fully demonstrate the correct behaviors.

After the participants completed the training sessions in the VR-FST environment, ISA (Real) phase was implemented in order to determine whether the participants transfered skills they gained in the virtual environment to real life. The real phase was carried out by a firefighter in an environment furnished to reflect a living room in a local fire department. In the training, the firefighter left the room with an announcement while talking to the participant about fire safety. The participant was left alone in the simulated room. After a while, a smoke effect was given from a fog machine hidden inside the room and then the fire alarm was activated by using the sound systems inside the building. At this stage, participants were observed only in the context of ISA. The scenarios used in the pre and post training applications and the target behaviors expected to be exhibited are shown in Table 4.

3. Results and discussion

In this section, the development of behavioral skills with VR-FST and the transfer of these skills to a real-world situations are discussed.

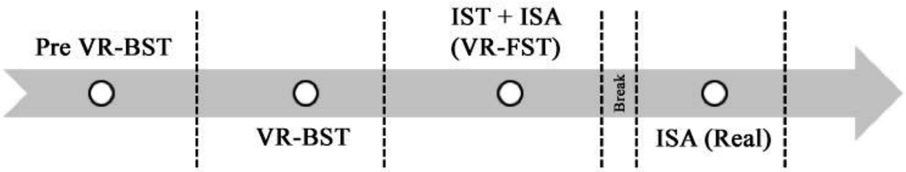

Fig. 5. Implementation process.

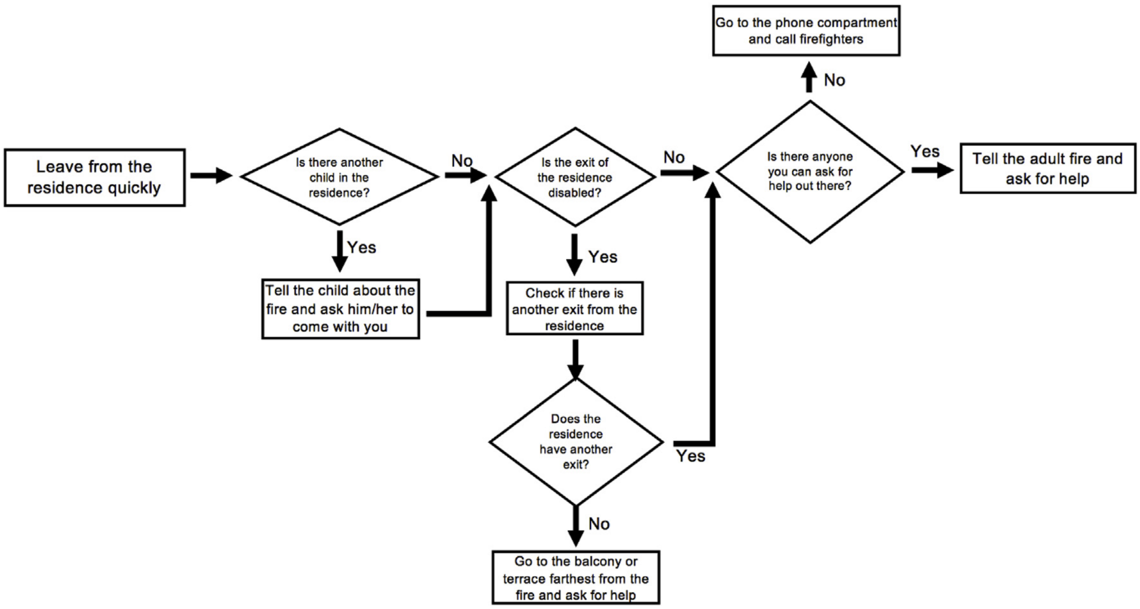

Fig. 6. Training scenarios.

3.1. Development of behavioral skills with VR-BST

Fig. 7 shows the results of the observations in the VR-FST environment.

Fig. 7 indicates that the accuracy of the behaviors displayed by P1 and P2 in the post-VR-BST were more correct than those in the pre-VR-BST. In the post-VR-BST section, P1 could display the expected behaviors in a complete and correct manner without any IST. P1 expressed her experience as: "*Since I had played similar computer games before, I thought that the fires I saw before training would not hurt me. In the training, I learned that the fire is very dangerous and that I should stay away. I stayed away from the fires I saw in the other house.*"

In the post-VR-BST section, IST was applied to P2 only once. During the IST, the firefighter reminded P2 that he should inform the adults about the fire after leaving the building. After IST, P2 was able to display the expected behaviors correctly without any intervention. In the interview done after the implementation, P2 stated that "*When I encountered a real fire before, I was shocked and couldn't decide how to behave. So, I started crying and waited for some help. Firefighters who came to extinguish the fire rescued me. In the training given here, staying away from the flames at the time of a fire was taught. So, when I saw a flame, I stayed away.*"

P3 had participated in a fire drill organized by firefighters at her school before the research. It was observed that P3 kept her avatar away from the flames and did not interact with the fire in all applications. P3 explained her misconduct before his training as "*It was fun to use HMD. I was really inside that house. I saw the fire but it was far from me. I thought I would find the hidden object until it came to me.*" After the training, P3 were exposed IST. First, the firefighter avatar came closer to her avatar and reminded her that she should inform the adults about the fire after leaving the building. Second, after encountering the fire, she was reminded that the building should be abandoned quickly and safely. After ISTs, P3 was able to perform the expected behaviors correctly.

P4's behaviors in the training were somewhat unexpected. When P4 encountered the fire for the first time, she continued to stay in the fire environment and entered into the fire. Also, in the 3rd and 4th applications, she ignored the fire and put her avatar in the flames. She acted as if there were no fire. She safely left the house informing loudly around about the fire in the first application. However, she did not ask for any help after going out. In this case, an IST was applied. In the 7th and 8th trials performed after IST, it was observed that the P4 performed the expected behaviors without any intervention. In the 9th trial, P4 kept her avatar away from the flames when she encountered fire, but remained in the fire without leaving the house. After the IST again, in the 10th and 11th trials, P4 performed correct behaviors.

The accuracy of the P5's behaviors before training was under the expected level. P5 attempted to investigate and extinguish the fire when she first encountered the fire in the VR-FST. It was observed that during the first three trials, she left the house in a safe way when she encountered a fire. However, after she left the house, she did not ask for help from an adult avatar who was there or did not call the fire department. In this case, applying the IST, P5 received feedback about asking help or calling someone and she successfully exhibited the expected behaviors in the 10th and 11th trials.

P6 with fewer computer game experiences has participated in a fire drill and a fire safety training before the study. During the implementation, P6 interacted with the fire by using his avatar in all the applications before the training. He ignored the fire and navigated as if there was no fire. In this sense, P6 expressed that "*I was using HMD for the first time. The flames seemed very real. There was even smoke. I wondered if the fire was real. I wanted to test if it would burn me.*" In the first trial after training, he kept his avatar away from the flames and reported the fire loudly after encountering the fire. Then, he left the house quickly using his avatar. However, he

Table 4
Practices and target behaviors.

Practice	Fire Situation	Target Behaviors
1–6	Finding an adult to ask help outside of the residence	1) The participant stays away from the flames after encountering the fire within the residence in the VR-FST. 2) The participant informs the fire with a loud voice. 3) The participant leaves the residence quickly and securely. 4) The participant goes to an adult who is outside the residence and informs the fire and asks for help.
2–7	Finding a phone compartment to ask help outside of the residence	1) The participant stays away from the flames after encountering the fire within the residence in the VR-FST. 2) The participant informs the fire with a loud voice. 3) The participant leaves the residence quickly and securely. 4) The participant goes to a phone compartment outside the residence to call the firefighter department.
3–8	Disabled of residential exit by fire	1) The participant stays away from the flames after encountering the fire within the residence in the VR-FST. 2) The participant informs the fire with a loud voice. 3) The participant leaves the residence using the other exit quickly and safely. 4) The participant goes to a phone compartment outside the residence to call the firefighter department.
4–9	All exits of the residence are closed/disabled during the fire	1) The participant stays away from the flames after encountering the fire within the residence in the VR-FST. 2) The participant informs the fire with a loud voice. 3) Participant quickly and safely goes to the balcony/terrace which is the farthest from the fire. 4) The participants asks for help by notifying the fire with a loud voice.
5–10	The existence of another child in the residence during the fire	1) The participant stays away from the flames after encountering the fire within the residence in the VR-FST. 2) The participant goes near to the other child in the residence and informs him/her about the fire. 3) The participant leaves the residence quickly and safely with the child. 4) The participant goes to a phone compartment outside the residence to call the firefighter department.
11	The existence of another child in the residence and all exits of the residence are closed/disabled during the fire	1) The participant stays away from the flames after encountering the fire within the residence in the VR-FST. 2) The participant goes near to the other child in the residence and informs him/her about the fire. 3) The participant goes quickly and safely with the other child to the balcony/terrace which is the farthest from the fire. 4) The participant asks for help by notifying the fire with a loud voice.
12 (Real)	The existence of a firefighter to ask for help outside the residence	1) The participant stays away from the smoke after encountering the smoke effect within the room. 2) The participant informs the smoke with a loud voice. 3) The participant leaves the residence quickly and securely. 4) The participant goes to a firefighter who is outside the residence and informs the smoke and asks for help.

didn't inform the adult avatar about the fire or ask for any help. After implementing IST, he kept his avatar away from the flames but continued to stay in the house and he asked for help loudly.

When P7 encountered the fire in the VR-FST environment for the first time, he kept his avatar away from the flames. However, P7 continued to stay in the fire instead of leaving the house. In the 3rd, 4th, and 5th trials he ignored the fire and put his avatar in the flames as if there was no fire. After the IST, he performed the expected behaviors. However, when he encountered the fire, he tried to pass his avatar through the flames in order to leave the house quickly. After applying IST again, in the 9th trial, he kept his avatar away from the fire but remained in the house. After applying IST again in the 10th and 11th applications, P7 was able to display the expected behaviors correctly. P7 expressed his experience as "*I had never had fire training before. So I couldn't remember how I had to behave.*"

P8 successfully performed the correct behaviors before the training. When P8 encountered the fire for the first time, she kept her avatar away from the flames and quickly left the house. In the 2nd and 3rd trials, P8 performed the behaviors expected from her in a correct way without any intervention after the VR-BST.

Overall, independent of the prior experiences about the fire, the training regarding VR-BST approach positively influenced the development of the participants' fire safety behavioral skills.

Thus, VR-BST may be used as an effective way to train the behavioral skills in the virtual reality environment. This result concurs with previous works on preparing educators for the development of security skills in various dangerous situations (Grabowski & Jankowski, 2015) and unrealizable educational scenarios (Smith & Ericson, 2009) in the virtual reality environment. Similarly, Padgett, Strickland, and Coles (2006) suggested that all children can complete safety steps at a high level of accuracy after skills

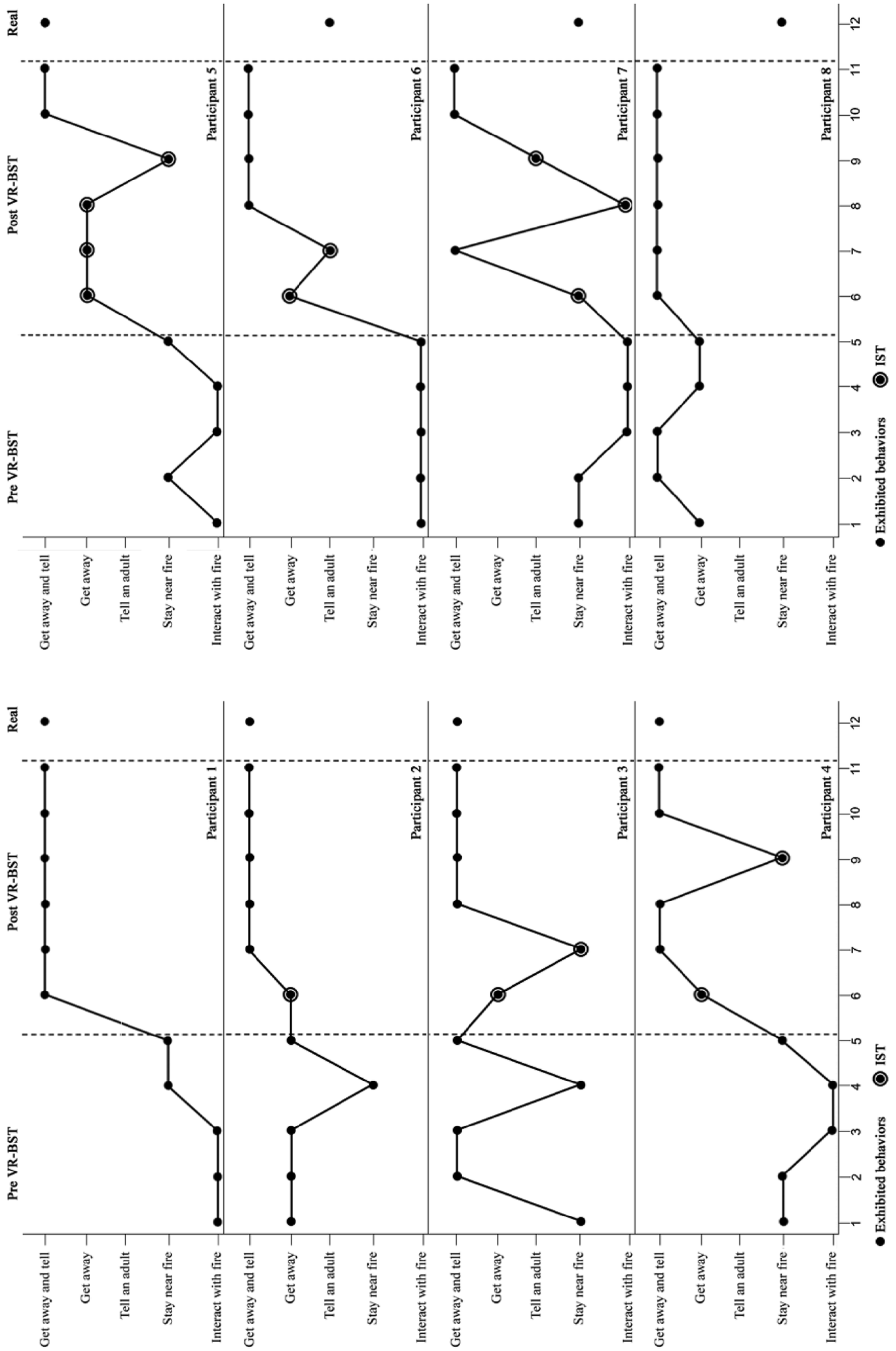

Fig. 7. Results from observations.

training for fire safety in a virtual reality environment.

The limitations of C-BST in interaction, reality, and active learning can be enhanced and learning environments that are closer to reality can be created with the VR-BST approach. At this point, non-immersive virtual environments served with C-BST can be enriched more immersively with VR-BST. In this study, presence in the VR-FST environment was enhanced by using HMDs and headphones. Thus, the difference in the sense of reality between the virtual environment and real life is reduced allowing participants to exhibit more natural behavioral responses. In this sense, P5 emphasized the reality in VR-FST as "*The houses in the environment were sufficiently real. The house was equipped similarly to the real houses. …I felt like there was a fire, I was really scared.*" In addition, P3 explained the reality as "*The objects were similar to the real life. The fires were the same as the flames in real fires.*" Similarly, P2, focusing on the sound, expressed that "*I felt like I was in the fire through the HMD. I could hear the fire sounds by using the headset.*"

Another contribution of the VR-BST approach is allowing the participants to improve their skills by acting in the environment many times by doing drill and practice. At this point, P2 expressed that "*I think training should be given through virtual reality environment with drills. With this kind of experiences, so they can easily adapt these skills to real life.*"

The VR-FST environment used in the research was designed on Second Life. Objects, effects, avatars, and navigation functions within the environment were provided using Second Life features. Therefore, the sense of reality and the level of interaction were applied as allowed by Second Life. In further studies, advanced virtual reality platforms can be used to create more real and interactive environments. As suggested by Smith and Trenholme (2009), the game engine technology which is promising in the sense that more realistic fire effect on fire safety training and simulator-based buildings for evacuation training can be provided.

In line with the qualitative data, it can be argued that VR-BST is capable of producing higher level of reality sense and this sense has a positive role on the development of the behavioral skills.

3.2. The effect of IST on VR-BST

In order to determine the effect of IST on VR-BST, behaviors exhibited by 2 participants were observed without any IST intervention. The behaviors exhibited by the participants are shown in Fig. 8.

Fig. 8 indicates that the accuracy levels of the behaviors exhibited in the VR-FST environment before training P9 and P10 who did not receive IST are not sufficient. Two of them had interacted with the fire at least once before applying IST. In the post-training, it was determined that they exhibited more correct behaviors than in the pre-training. However, the accuracy level of the behaviors varied regarding the fire scenarios they encountered. The feedbacks in the IST are also considered to play an important role in correcting the behaviors.

It is observed that participants who received IST during their practice showed more correct behaviors than others. For instance, P2 was unable to report the fire after leaving the building in the first trial in post training. After IST, in all other trials he displayed correct behaviors. Similarly, P3 exhibited incorrect behaviors in the fire environment during the trial 7. After IST, she went away from the flames and left the residence quickly when encountering a fire during the rest of the trials. In accord with the findings of this study, some other studies also point out that the skills training will be more effective when BST is applied together with IST (Dancho

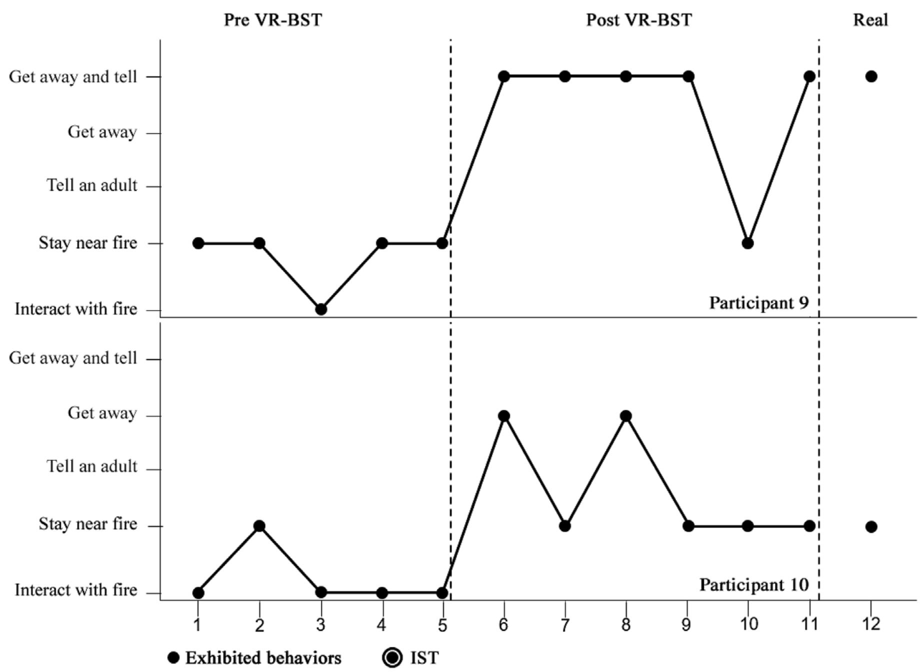

Fig. 8. Observation results for participants who did not apply IST.

et al., 2008; Gunby, Carr, & LeBlanc, 2010; Himle et al., 2004; Johnson et al., 2006; Jostad et al., 2008).

In the design phase in this study, the skills were modeled by dividing them into sub-behaviors, planning scenarios regarding these sub-behaviors and designing VR-FST through these scenarios. Hence, the suggested VR-BST approach can be considered not only as a contribution to the design side of virtual reality environments but also to the implementation and evaluation sides. At this point, BST which is as a basic framework for C-BST was reshaped in this study in the direction of embedding it with virtual reality learning environments and using it for fire safety.

3.3. Transferability of behavioral skills to real life

Padgett et al. (2006) emphasizes that it is necessary to generalize the safety skills acquired through computerized methods in real-life situations. Considering the fire safety training, the adaptation of the scenarios that can be created in the virtual environment to the real-life conditions involves both life threat and the material damage. In this study, a real residential fire situation was created using a room equipped with a television, designed residence hall, a smoke-effect, and a fire alarm component. It was observed that 6 participants could transfer the skills they acquired in VR-FST environment to real life conditions completely and correctly. This result overlaps with the idea in different researches that the behavioral skills acquired in the virtual reality environment could be transferred to real life (Grabowski & Jankowski, 2015; Ip et al., 2018; Self, Scudder, Weheba, & Crumrine, 2007). During the real practice, 4 participants waited for help without leaving the room. It was found that feelings of excitement and fear positively influenced the behaviors exhibited during the real practice. For instance, P10 could not transform his learning into behavior either in the virtual reality environment or in the real practice as IST was not applied to her. Thus, P10 continued to stay in the room although he felt the smoke effect and explained this as; after the real practice, he was very excited when faced with the smoke effect and stayed in the room because she panicked.

The findings of this study indicate that the different personal background knowledge does not affect the transferability of behavioral skills to real life. The participants' computer game and fire safety experiences somewhat influenced the development of behaviors trained in virtual reality environment. Similar to the findings of Smith and Trenholme (2009), in this study, participants with more experiences in computer games and in the fire safety could perform behaviors more accurately than the others.

PQ scores and responses to the interviews indicate that most of the participants perceived the VR-FST environment as real. Table 5 shows the responses of the participants to the PQ applied after the VR-FST training.

In this line of reasoning, Table 5 indicates that the sense of reality and the level of interactivity are important in terms of feelings of presence. It was determined that the participants who could transfer their behavioral skills to the real environment perceived the VR-FST as sufficiently real and experienced a high level of presence. In accord to this finding, there are several studies reported that when the sense of reality in virtual reality environments for educational purposes is high, the skills to be acquired can be transferred more to real life conditions (Parsons & Cobb, 2011). In addition, the compatibility of the real practice environment and the virtual reality environment with each other positively contributed to the exhibition of the skills in the real environment.

It was found that all of the participants scored above the average level from the PQ. In this direction, it can be inferred that the VR-FST environment is perceived as sufficiently real and the participants felt themselves as they were in the actual environment during the practices. The highest score average was Sensory Fidelity factor and the lowest score average was Interaction. Thay is to say, interaction with the VR-FST environment does not mean perceive the environment as sufficiently real for every students. On the other hand, participants with a higher overall PQ average score could transfer their skills acquired in the VR-FST environment into more successful behaviors during real practice. Therefore, it can be concluded that the perception of reality level of the VR-FST environment plays a decisive role in the transferability of the skills acquired in the virtual reality environment to real-life conditions.

4. Conclusions

In this study, the effect of virtual reality-based behavioral skills training approach is tested on acquiring behavioral skills for fire safety. The transferability of the behaviors to real life conditions is also investigated. The results are summarized as follows:

Table 5
PQ average scores.

Participants	Involvement	Adaptation/Immersion	Sensory Fidelity	Interaction	Interface Quality	Average	Real Practice
P1	4.89	4.86	4.60	4.40	3.67	4.62	4
P 2	4.78	5.00	5.00	4.60	5.00	4.87	4
P 3	4.44	4.14	4.60	3.80	5.00	4.35	4
P 4	4.22	4.43	4.40	3.80	4.00	4.21	4
P 5	4.66	3.71	5.00	4.00	4.33	4.35	4
P 6	3.89	3.57	4.20	3.20	2.67	3.63	2
P 7	4.67	4.71	4.20	3.60	3.67	4.32	1
P 8	4.33	3.86	5.00	4.40	4.33	4.35	1
P 9	4.44	3.57	4.80	3.20	3.67	4.00	1
P 10	4.78	5.00	4.60	4.20	3.67	4.59	4
Average	4.62	4.29	4.80	3.96	4.33		

- Behavioral skills towards fire safety can be improved with virtual reality-based fire safety training (VR-FST) environment developed within the framework of VR-BST approach. In this context, when VR-BST is applied with in situ training (IST), more positive learning outcomes can be provided in terms of developing behavioral skills towards fire safety. The contribution of IST can be more positive when the IST performed in the VR-BST and the IST in real life situations are compatible with each other.
- Skills acquired through VR-BST based training could be transferred to real life conditions with high accuracy. In this sense, virtual reality used for behavioral skills training can provide the development of the behavioral skills and improve their transferability to real life conditions.
- The level of sense of presence in virtual reality based learning environments plays a crucial role on the transferability of skills acquired in virtual reality environment to real life conditions.

Overall, in this research, behavioral skills training for dangerous conditions in real life is conducted through an immersive virtual environment. In the behavioral skills training to be carried out through virtual reality environments, the level of immersiveness presented by the environment and the sense of presence experienced by the participants are key factors effecting the developments of the behavioral skills. In this direction, virtual reality environments should be designed in a more realistic and immersive way. On the other hand, support of BST to be applied in virtual reality environments with IST is important for empowering the correct behaviors. The study confirmed that when VR-BST is applied with IST, the behaviors can be exhibited more accurately. In addition, Grabowski and Jankowski (2015) asserted that the positive effects of skills acquired in virtual reality environments are continued to be seen even after 3 months. Future studies will focus on ensuring the sustainability of exhibiting correct behavioral skills. Consequently, the results indicate that VR-BST can be used as an alternative approach for behavioral skills training where perceived reality can be experienced at a higher level. We hope that the findings of this study will assist in the future design and implementation of immersive virtual reality based learning environments and also the use of BST in virtual learning environments.

Conflicts of interest

The authors declare that they have no conflict of interest.

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