Intelligent Behaviors of Virtual Characters in Serious Games for Child Safety Education

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Abstract The child safety education is a very urgent task in China. It is necessary to teach children to recognize unsafe factors and learn how to escape from a dangerous situation. According to the psychological characteristics of children and constructivist learning theory, 3D serious game is an effective tool to assist child safety education in primary and secondary schools. In this chapter, we summarised some of our explorations in this field. We proposed a concept of the danger zone to simulate users' risk-taking behavior; introduced Non-Player Character's (NPC) role to increase user engagement; and developed a cognitive model that could simulate the intelligent behavior of virtual agents. We also tested cases of escaping from waterside area and earthquake. Results showed that children enjoyed this new safety educational method and learnt what a danger zone is and how to escape from the danger zone effectively.

Keywords: child safety; 3D; serious game; safety education; virtual character

1. Introduction

Currently, there are nearly 220 million children under the age of 14 in China. The science education is essential to the healthy development of children [1] [2]. An important aspect of science education for children is child safety education, which is not only for children, but also for their parents. For a long time, both children and their parents pay little attention to the safety. Unintentional injuries among children happen very often and remain high in China. With the continuous expansion of social living space, the potential risk of child unintentional injuries is rising; and the types of injury are increasing. According to statistics provided by Traffic Management Bureau, Ministry of Public Security of China, there are more than 18,500 children under the age of 14 died in road traffic accidents every year. The death rate is 2.5 times of Europe and 2.6 times of the United States. In traffic accidents, more than three-quarters of children are injured on the road.

In primary and secondary school, most students receive their safety education by learning regulations and accident cases through safety training videos. This inculcation education only tells children what not to do, without teaching them how to deal with the specific case. It is difficult to attract children's interest. Moreover, most of the existing child safety education books, even multimedia educational materials, are still using the traditional education mode, without any interaction. Take traffic safety education as an example, it is difficult for children to have direct perception of safety through the traffic rules. They prefer visualization method as their logical thinking ability is not yet fully developed. Psychologist Piaget [1] explained this phenomenon, as children's knowledge mainly comes from the cognitive construction of the objective world [2]. Therefore, setting up a learning situation is very important to increase learners' interest. We can get rid of cramming education model by a specific scene to help children construct specific safety knowledge. We used to demonstrate safety topics with 2D interactive animations [3], but it is not an ideal way to provide a sense of immersion. Interactive 3D animation utilizes cartoon creations to visualize event's consequence with interactive computer animation technology. With the rising of cost performance ratio of computer hardware, interactive 3D animation and games become widely adopted in education. Vivid teaching software could be developed with interactive 3D animation. Comparison with 2D animation technology, in-

teractive 3D animation and games can effectively enhance the user's sense of immersion and help the user achieve learning outcomes.

Previous games on earthquake or tsunami survival are mainly Flash-based with trivial game mechanics such as running and rebuilding after disasters. We designed a few serious games for child emergency escape education. In these games, we adopted cognitive models in character design to simulate their behavior. We developed a rural waterside safety educational game and an earthquake escape game for children to improve their recognition skills about unsafe factors. Evaluation showed that these serious games raised children's safety awareness and had great potential in child safety education.

2. Current Serious Games for Safety Education

Serious games with highly realistic scenes have been used as adjuvant psychological therapy, fire escape training and military training [4] [5]. For example, Padgett et al. [6] developed a virtual reality computer game to teach fire safety skills to children diagnosed with fetal alcohol syndrome. Smith et al. [4] helped children to learn fire safety skills with a less interactive game.

Building Information Modeling (BIM) was used in a fire escape serious game [7] to represent an accurate architectural 3D space for escape. The development trends for serious games include having more intelligent NPCs and more realistic 3D scenes; effective use of BIM; utilizing various methods of physically based simulation, fluid simulation, collision response and other effects in real-time. A serious game can be a visual assistant tool for emergency training. With the popularity of Head-Mounted Display (HMD), serious game scenes become more immersive and realistic. Chittaro *et al*. [8] developed a HMD based prototype of a serious game to simulate how passengers react to hijackers in the airplane. As users' experience could be enhanced by the realistic scene, this game can be used in the education to prevent terrorism. Jaziar [9] used serious game to carry out fire evacuation education. Users could experience the evacuation at different conditions (flame, smoke and temperature). Luca [10] designed a serious game for

terrorist attacks that occurred in a train station to investigate mass psychology in emergency.

Serious game development requires an interdisciplinary endeavor. Psychology and artificial intelligence are becoming new selling proposition of serious games [11]. It is realized that one of the technological innovations of next gen games would be modelling emotions [12]. However, only a few games have done this, e.g. "The Sims" is a game that simulates mental activities for characters. Designers used hungry, physical strength, comfort, health and other human variables to describe emotions of characters. The game referred to the big five personality from its psychology model. If the characters in a bad mood, they would refuse the player's command and express their emotions. The personalized interaction between characters in the virtual society increased the interest of the game. The success of "The Sims" indicates that creating virtual characters with rich emotion expressions will be a core technology for animations and games.

3. Risk-taking behaviors and Danger Zone

Human behaviors are closely related to the environment. Thus, risk-taking behaviors generally occurred in a danger zone. We collected all kinds of children's accidental injury cases in recent years. By analyzing these cases, we found that majority of accidental injuries occurred due to poor knowledge, ignorance, or lack of awareness about safety measures for accident prevention. This paper presents the concept of the danger zone, which refers to the specific area in children's living space. Once children enter these areas, their behaviors can easily cause harmful events with objects in the danger zone. The reason children's accidents happen frequently is that people lack sufficient knowledge of the danger zone. Some danger zones do not constitute dangers for adults but will cause fatal injuries for children. For example, on 4 October 2010, in Jiangbei district, Ningbo, China, a 2-year-old boy, who has just learned to walk, wanted to wee in his potty when adults were away. Unfortunately, he slipped when opening the lid of the potty and stuck his little head in the potty. Finally, firefighters had to come to rescue. In this

case, parents may not realize that potty would get stick in a child's head. If so, they would have taken precaution to prevent the accident.

The danger zone should be considered in child safety serious games to achieve the learning outcomes. Children should be allowed to explore and learn from mistakes in a safe environment. By constructing different security virtual scenes, children can roam in a 3D virtual space and control avatar's behavior in these scenarios. Different accidents can be simulated in the game environment. These virtual experiences of accident scenes and animation effects will effectively stimulate students' interest to obtain knowledge about the safety precautions (Fig. 1 and Fig. 2). For example, a dropped wire near the pole usually puts children at risk of electric shock. In order to help children identify these hazardous areas and risk-taking behaviors, serious game can simulate similar scenarios and corresponding results. Fig. 1 shows a scenario about a dropped wire. Once the virtual character approaches the wire, the game will remind children about the risk of electric shock. If the user insists on touching the wire, he will see the horrible consequence on the screen. In the trial we found that children liked to venture in the virtual scene and were impressed with the virtual experience of accidental injuries. Our evaluation confirmed the feasibility of using 3D games to support child safety education.

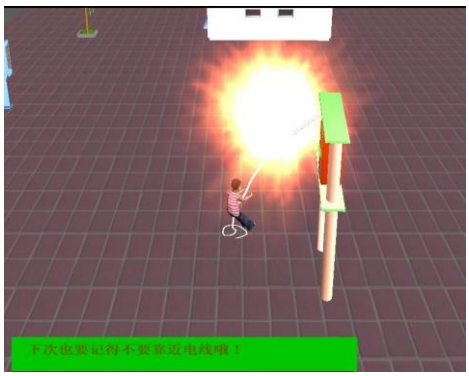

Fig. 1. Danger zone around a dropped wire. The consequences is displayed if a child touches the wire.

Fig. 2. The danger zone grows in fire. The player needs to put out the fire with fire extinguisher before passing through.

We will take road safety as an example to explain our game design. In this security theme, user can control the direction and status of child's movement by keyboard and mouse. The danger zone is set on a road, if the child deliberately delayed the time to cross the road (i.e. lingering around in the middle of the road when the traffic light turns green), a virtual traffic accidents would occur (see Fig. 3). The player can repeatedly experience the scene to find out a correct way to cross the road. Objects do not need to be presented at their actual size in the game. According to the educational needs of the theme, important traffic symbols can be presented with different colors and exaggerated shapes.

Fig. 3(a). A child does not move and stands in the middle of the road.

Fig. 3(b). The consequence: the child was hit by a car.

4. Behavior Design for Virtual Characters

We found some children preferred to take adventures while playing the safety educational game. They would intentional break traffic rules and take a variety of dangerous actions. To prevent these actions, Non-player characters (NPC) were introduced in the game. These NPCs would warn the player of dangerous actions with prompt messages (see Fig. 4).

Fig. 4 (a) Non-player character warns the user not to run a red light

Fig. 4 (b) A NPC prompts the player to call emergency numbers.

In order to enhance the games experience, NPCs should have believable behaviors. A cognitive model is established for the NPC's perception and behavior [13]. It is used to guide NPC's autonomous behavior. The NPC's general cognitive structure is shown in Fig. 5. An NPC will receive stimuli from the environment with sensors such as vision, hearing and smell. The stimuli will then be transferred to the perceptron and be interpreted semantically by a knowledge base, which is called by the perceptron. Based on the NPC's motivations, social norms and personality, the NPC would select the most appropriate response from the action list in the knowledge database that suitable for the current situation. This proposed cognitive model can simulate human cognition, reasoning and decision-making processes.

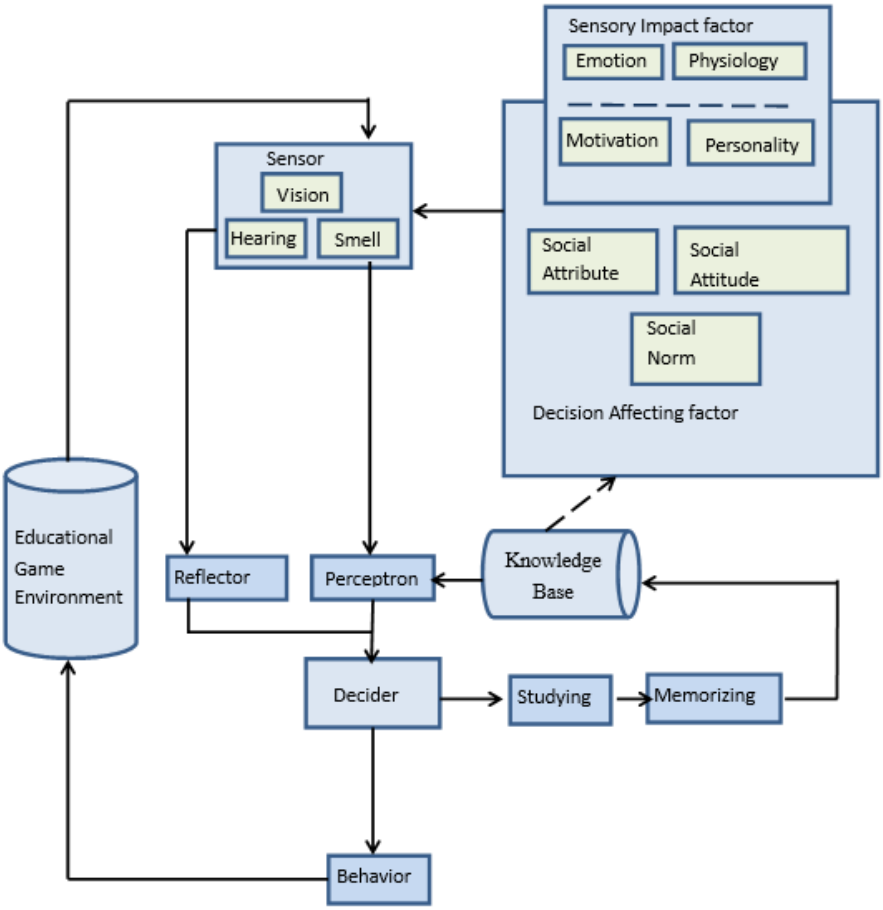

Fig. 5. Cognitive structure of a NPC

We can create different cognitive models for different game scenarios and simulate perception functions in different scenarios to describe the NPC's perceptron. Decision affecting factors in Fig. 5 can affect perceptron. The factor of social attribute can be replaced by NPC's social identity. The list of social identities can be used to identify the NPC's social relationships and perform specific behavior in a specific scenario. For example, in the scenario of hospital fire escape, NPCs who have family relationship will try to escape together. In this scenario, the perceptron of the NPC will apperceive his family members before practicing his escape plan.

Social norms are value standards of an individual's social behavior. It can be used to measure and judge the social impact of individual's behavior. People's social behaviors need to be constrained by social norms as they have direct impact on social life and social order. Therefore, use social norms in serious games will help create NPC's complex behavior. Social attitudes can be regarded as one's acceptance of social norms. People who accepts social norms will generally constrain their behavior by social norms.

In this chapter, we mainly discuss two attitudes that impact on NPC's decision-making: obeying or rejecting social norms. For example, patient safety is nurses' first requirement in emergency. Social norms require them to help and guarantee patient to escape from the dangerous situation. Therefore, nurses who obey social norms will not escape by themselves but help patient to escape first. On the other hand, nurses who do not obey social norms will escape by themselves and leave patient alone.

Additionally, psychological variables like motivation, personality and emotions also have impacts on the NPC's decision-making. However, relevant researches in this area are insufficient so far. Psychologists point out that motivation is the internal driving force of human behavior. Using motivation module in serious games can indicate the internal driving force of NPC's behavior. Maslow's hierarchy of needs reflects the common law of human behavior and mental activities [14]. He portrayed human needs in a five-level hierarchy: physiological, safety, love/belonging, esteem and self-actualisation.

Safety needs and love/belonging needs affect people's evacuation behavior in unexpected disasters. Based on the safety needs, people will choose to escape in the event of unexpected disaster. However, their choice will go beyond safety needs if they have love/belonging needs about family affection. For example, at the time of the earthquake, most people would escape to the exit as soon as possible. Under the influence of family affection, some parents won't escape until they find their children.

Personality forms the basis of our predictions concerning NPC's future behavior in given situations. Researchers generally agreed that the big five personality traits "OCEAN" is the widely examined theory that can describe personality. According to this theory, people's personality is divided into five types: openness, extraversion, conscientiousness, agreeableness and neuroticism [15]. Each factor

has positive and negative values. O+ refers to open mind, curiosity, creativity and wide interests, whereas O- refers to closed mind, caution and resistance to change. C+ refers to self-discipline, sense of duty, leadership quality and persistence, whereas C- refers to irresponsibility, carelessness and shrink. E+ is perceived as extroverted, talkative and sociability and E- is perceived as introverted, shy and aloof. A+ means friendly, submissive and cooperative, while A- is perceived as detached and antagonistic. N+ is perceived as sensitive and unstable while N- refers to stability and calm.

While dealing with emergencies, people with O+ (open-minded) and C+ (responsible) can reasonably use a variety of countermeasures. They will be more patient, more curious and more eager to explore new situation. They won't be flurried and overwhelmed for the sudden change, but can effectively respond to the change and make best decisions for the current situation. Whereas people with E- (aloof), A- (unsocial) and N+ (sensitive), are more likely to have extreme behavior, such as jumping off the building, when dealing with unexpected disasters.

Emotion is another important attribute of an NPC. As it will affect one's behavior, a believable NPC behavior model should take it into consideration. Among many emotion models, OCC model, PAD model [16], EMA model [17], are the most popular. The PAD model uses dimensions to represent all emotions. The P (Pleasure) scale measures how pleasant or unpleasant one feels about something; the A (Arousal) scale measures how energized or soporific one feels; and the D (Dominance-Submissiveness) scale represents the controlling and dominant versus controlled or submissive one feels. In the PAD model, values for three dimensions are in the range of [-1, 1]. There will be eight subspaces to define the type of emotion according to their emotional qualities.

EMA model based on emotional cognitive psychology, it regards emotion as the evaluation of events. In the EMA model, "Desirability" and "Likelihood" are the evaluative variables. They can get corresponding value according to the environmental evaluation assessed by the perceptron. "Desirability" associated with the goal of subject while "likelihood" refers to the expectations for the event. Each evaluation variables has its value. The value of "desirability" includes "desirable" and "undesirable". When a certain event could help the subject to achieve their goals, it is desirable; otherwise, it is undesirable. Similarly, the value of "likelihood" could be *unlikely*, *likely* or *certain*. Different values of evaluation variables

and their combinations can result different emotions, which provide a theoretical basis for constructing emotional inference rules.

In our serious games, NPC emotions can be triggered by a perceptible object in the scene or an activating event, also known as the source of those emotions. Over a period of recovery time, emotion would gradually return to the baseline level of state (calmness). Each source has an emotional impact on the NPC. Emotion would be generated by a perceptible object in the scene or an activating event, and would affect the NPC's perception ability in reverse.

We use fuzzy productive rules to design the decider [13]. Based on cognitive appraisal theory of emotion, a set of productive rules for NPCs could be used for different game themes. The premise of the rule is the knowledge of the status of appraisal variables and decision impact factors. The conclusion of the rule results various behaviors, including emotions.

5. Evaluation of the Child Safety Games

5.1 Waterside Safety Game

We created a scene of a typical Chinese Jiangnan style village and a waterside landscape as the game scenario. The virtual character can be controlled either by game AI or by the player as an avatar to increase the user engagement. When controlled by game AI, the virtual character has autonomous behavior and can react to other approaching virtual characters. There are two modes to control the character. In the *autonomous* mode, the character will automatically roam in the scene. Users can follow the character from different perspectives. The *user-controlled* mode allows the player to fully control the avatar. Autonomous mode can be used to demonstrate the safety education game. Different objects in the scene would be given different preset semantic information to instruct the virtual character how to perceive them. For example, when the character perceives a fruit stand, he would obtain semantic information "something edible" (associated with physiological needs). The character would then make the appro-

priate behavior that is driven by the motivation. He may stop and look, see Fig. 6. When the character perceives a stray dog, they would obtain semantic information "something dangerous" (associated with safety requirements). The character would then run away (Fig.7). When the character is around a boat and *sees/hears* someone fell into the water, he would get speedboat's semantic information "something for rescue" (associated with belonging needs). The character would drive the speedboat to save the drowning victim (Fig.8).

Fig. 6. The character stopping and looking at the fruit stand

Fig. 7. Escaping panic when encounter a stray dog

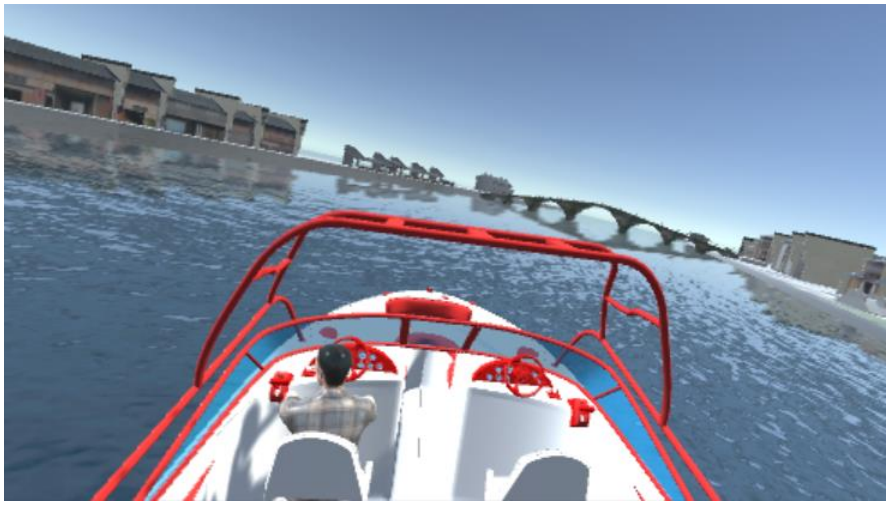

Fig. 8. Driving a speedboat to save a drowning victim

In the user control mode, users could explore potential risks in the virtual scene by themselves.

In order to investigate how many security risks children can learn from the game, we designed a risk assessment questionnaire and an experiment, which was conducted at Zhenan Road Primary School in Ningbo. 98 participants aged 12 played the game and completed the questionnaire.

Having investigated several village safety problems in the game, we found that bitten by dogs was regarded as the most dangerous factor (36 participants agreed), followed by water safety (32 participants agreed), as shown in Fig. 9. Survey results showed that students are aware of all safety problems in the game as we expected. Therefore, it is meaningful to raise students' awareness of safety with our educational game.

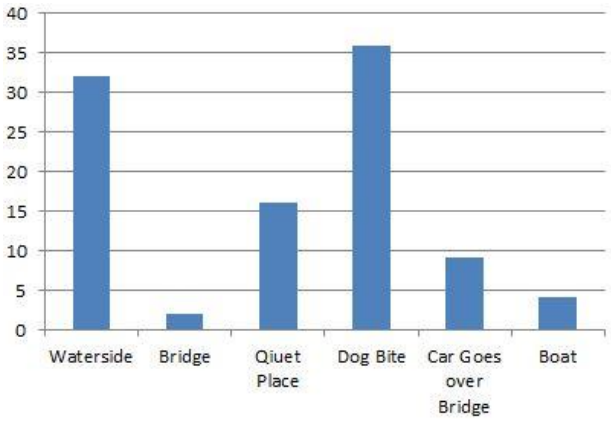

Fig. 9. Hazards identified in the risk assessment survey

We also investigated children's reaction to the danger. The results showed that when a child falls into the water, 85% of participants would use boat to save the victim and 15% would find a doctor. That indicated that the participants had high awareness of water safety.

5.2 Earthquake Escape Game

China is an earthquake-prone country. Using serious game to aid earthquake escape education has a considerable realistic significance in China. We model a 3D hospital scene of the affiliated hospital of School of Medicine in the Ningbo University. In the game scene, users can observe events that may occur in an earthquake from the first person perspective; NPCs are designed to help users to learn the knowledge of escape. A variety of collapse and fragmentation effects are achieved based on the physical model and the flame effect is simulated with particle animation (Fig. 11). When the earthquake occurs, the avatar is in the hospital waiting room (Fig. 10), he may want to take escalator to go downstairs. If so, an NPC nurse will come to remind the user to use the stairs instead (Fig. 12). When the player is blocked by fire, he will receive a text prompt to find the nearest fire extinguisher. Once he got the fire extinguisher, he will get instructions on how to operate the equipment and so on. To make the game more interesting, we present a health bar for the character. If the virtual character is injured or stayed too long in

the smoke, his health will be reduced. When the health reaches zero, the character will fall and die. Using this mechanism, we added a sense of urgency and ask the player to flee the outpatient building as soon as possible. This also discourages the exploration behavior of some players who try to test the limits of the game and experience various options.

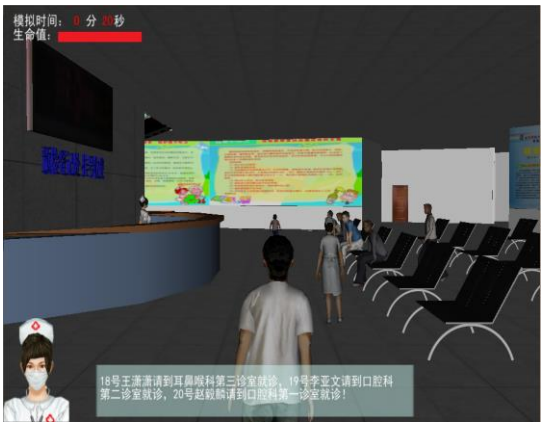

Fig. 10. The character in a hospital waiting room before the earthquake

Fig. 11. After the earthquake, fire caused by electrical short circuit

Fig. 12. An NPC nurse advises the player not to take the escalator

By analyzing students' game play in the earthquake scenario, we found that when the earthquake occurs, 6% of students would stand still, 62.2% of them would run to the escape stairs and 31.8% of them would feel overwhelmed and walk around. When encountered with the fire, 92.8% will walk around it or find a fire extinguisher to put out it. But there are 7.2% of players were not aware of the dangers and tried to pass through the fire without any protection.

We also discovered that boys were more likely to keep on going when they face a dangerous situation than girls. For example, instead of walking around, some boys will go into the fire and the black smoke directly. Therefore, we added the health bar for the virtual character in the game to discourage adventures. Once they stayed in the dangerous environments or touched hazardous objects, their life values would be reduced. If the virtual character jumped off the building or is injured by a falling object, he will lose some health values. More seriously, the character would die if his health becomes zero. This may visually show the importance of escape.

The purpose of this educational game is to enable students to learn basic knowledge of earthquake escape, aware of the dangers that exist in the earthquake, as well as serious consequences that caused by improper behaviors. After experience the escape with the earthquake escape game, we found that pupils had a better understanding of the dangers and learned the basic knowledge of escape and simple precautions that can help them survive.

We did a survey among students who have played above two games. When they were asked whether they are able to deal with the real danger similar with the ones they experienced in the games, 62% of students said yes, 9% of students said no, 10% said they had no idea and 19% said they might (See Fig. 13). The result showed that after playing the safety education games, pupils' escape knowledge and safety awareness have increased significantly.

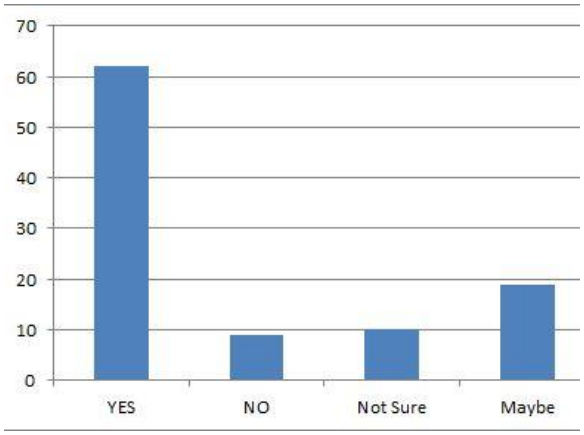

Fig. 13. User learning effect statistics

In summary, safety education with serious games will have remarkable effect and are more engaging than traditional methods of safety education. This method can attract children's interest and raise their safety awareness. Players will learn escape knowledge unconsciously by playing the games. It is feasible to use game as an educational tool to raise awareness of child safety and to increase disaster and emergency preparedness.

6. Conclusions

It is a meaningful work to use serious gaming technology in child safety education. This chapter summarizes some of our explorations in this field. We proposed the concept of danger zone on the basis of analyzing children's accidental injury cases in China. According to children's psychological characteristics, 3D serious games

were developed to assist child safety education in primary and secondary schools. To increase the interactivity and interest, we proposed a cognitive model and used it to design game characters with believable behavior. A water safety educational game and an earthquake escape game were designed based on actual accident cases. The player could roam in the game scenes; experience the importance of safety by exploring (trial and error) and obtain visual impression of the danger. Trials have been carried out in 40 primary schools in Ningbo, China (Fig. 14). Students liked this new safety education method very much. The proposed method is a reference for further development of child safety educational games.

Fig. 14. Trials of the child safety games in a primary school

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References

[1] Piaget J. and Inhelder B. (1969) The psychology of the child. Basic books, New York.

[2] Leslie, P.S., Steff, G. and Jerry, E.G. (1995) Constructivism in education, Lawrence Erlbaum Associates, Inc, Hillsdale.

[3] Liu, Z. (2006) Design of a Cartoon Game for Traffic Safety Education of Children in China. In Edutainment 2006, LNCS 3942, Springer Publisher, 589-592.

[4]Smith S. and Ericson E. (2009) Using immersive game-based virtual reality to teach fire-safety skills to children. Virtual Reality (S1359-4338), 13(2): 87-99.

[5]Luo L, Yin H, Cai W, Lees M, Othman N.B. and Zhou S. (2014) Towards a data-driven approach to scenario generation for serious games. Computer Animation and Virtual Worlds, 25(3-4), 393-402.

[6]Padgett L S, Strickland D, Coles C D. Case study: using a virtual reality computer game to teach fire safety skills to children diagnosed with fetal alcohol syndrome [J]. Journal of Pediatric Psychology, 2006, 31(1): 65-70.

[7] Ruppel U, Schatz K. (2011) Designing a BIM-based serious game for fire safety evacuation simulations [J]. Advanced Engineering Informatics, 25(4), 600-611.

[8] Chittaro L. and Buttussi F. (2015) Assessing Knowledge Retention of an Immersive Serious Game vs. a Traditional Education Method in Aviation Safety. IEEE Transactions on Visualization and Computer Graphics, 21（4）: 529-538.

[9] Jaziar R, Mehdi B L, Ole-Christoffer. Fire Simulation-Based Adaptation of Smartrescue App for Serious Game: Design, Setup and User Experience. Engineering Applications of Artificial Intelligence, 2015, 46, Part B, 312-25.

[10] Luca C. and Riccardo S. (2015) Serious Games for Emergency Preparedness: Evaluation of an Interactive vs. A Non-Interactive Simulation of a Terror Attack. Computers in Human Behavior, 50, 508-519.

[11] Ma, Minhua, Oikonomou, A., and Jain, L. (Eds.) (2011) *Serious Games and Edutainment Applications*. Springer: UK. ISBN 978-1-4471-2160-2, 504 p.

[12]Liu, Z., Pan, Z.G.: An Emotion Model of 3D Virtual Characters In Intelligent Virtual Environment. In: Tao, J., Tan, T., Picard, R.W. (eds.) ACII 2005. LNCS, vol. 3784, pp. 629–636. Springer, Heidelberg (2005)

[13] Liu Zhen, Hong Yuan, Liu Qiong, Chai Yan Jie (2011) An emotion model for virtual agents with evolvable motivation. Transactions on Edutainment VI, 154-163.

[14] Maslow A. (1954) Motivation and Personality. New York: Harper.

[15] Su, W.P., Pham, B. and Wardhani, A. (2007) Personality and emotion-based high-level control of affective story characters. IEEE Transactions on Visualization and Computer Graphics, 13(2): 281-292.

[16] Mehrabian A. (1996) Pleasure-arousal-dominance: A general framework for describing and measuring individual differences in temperament. Current Psychology: Developmental, Learning, Personality, Social, 14: 261-292.

[17] Jonathan Gratch, Stacy Marsella (2004) A domain-independent framework for modeling emotion. Cognitive Systems Research, 5(4): 269-306.