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The effect of game–based immersive virtual reality learning environment on learning outcomes: designing an intrinsic integrated educational game for pre–class learning

Aili Shi, Yamin Wang and Nan Ding

Beijing Key Laboratory of Learning and Cognition, College of Psychology, Capital Normal University, Beijing, People's Republic of China

ABSTRACT

As an emerging learning platform, game-based immersive virtual reality learning environments (GIVRLEs) have the potential to solve difficult teaching problems. This study designed a GIVRLE by integrating knowledge of quadratic functions into gameplay. Forty seventh graders who had never acquired that knowledge played the game and took pre- and posttests. An additional 60 seventh graders took the same math tests as controls. The results showed significant improvements in math achievement and learning motivation between the pre- and posttests among students who played the game. No enhancement of math achievement was found in the control students. The playability survey and user experience questionnaire verified the suitability of the game. The findings indicate that a GIVRLE is a suitable tool for addressing teaching difficulties in K–12. The notion of intrinsic integration between learning content and gameplay based on simulated daily activity tasks is further discussed.

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Augmented and virtual reality; games; secondary education; improving classroom teaching; interactive learning environments

1. Introduction

Many studies have explored and confirmed the value of virtual reality learning environments (VRLEs) for promoting user engagement, presence and usability (Dalgarno & Lee, 2010; Faiola, Newlon, Pfaff, & Smyslova, 2013; Ke, 2013; Lee, Wong, & Fung, 2010; Maitem, Cabauatan, Rabago, & Iii, 2012; Merchant et al., 2012; Mikropoulos & Natsis, 2011; Roussos et al., 1999), and for concretizing abstract concepts or ideas in learning content (Mikropoulos & Natsis, 2011; Pan, Cheok, Yang, Zhu, & Shi, 2006). Recently, game–based VRLEs, where learning content is incorporated into gameplay, have attracted much attention among researchers due to their combination of usability and likability (Maitem et al., 2012; Virvou & Katsionis, 2008; Xu & Ke, 2016). With the rapid development of virtual reality techniques, immersive VRLEs can potentially outperform 2D or 3D desktop virtual learning systems in terms of user experience (Dalgarno & Lee, 2010), and game–based immersive virtual reality learning environments (GIVRLEs) can significantly change education. To achieve the goal of being an effective and active learning environment, two aspects must be taken into consideration: 1) intrinsically integrating learning content into gameplay to improve GIVRLEs playability (Habgood & Ainsworth, 2011) and 2) practical concerns in current teaching practice (Vaiyavutjamai & Clements, 2006; Zaslavsky, 1997). After all, the evidence that game–based learning is not fully accepted in mainstream education needs more consideration. Operationally, whether GIVRLE can be accepted by teachers and students depends on whether it helps solve actual problems in learning and teaching and whether it can avoid game addiction.

CONTACT Yamin Wang wangym@cnu.edu.cn

For this case study, we designed a GIVRLE to address quadratic functions knowledge among average students. While such knowledge is generally abstract, complex and uninteresting for students, it is extremely important for math learning in junior high school. Many researchers have investigated such teaching–related problems (Nishizawa, Yoshioka, Pesonen, & Viholainen, 2012; Vaiyavutjamai & Clements, 2006; Zaslavsky, 1997; Zazkis, Liljedahl, & Gadowsky, 2003). In China, the idea of symbolic–graphic combination is commonly viewed as the most difficult aspect of math teaching (Huang, Li, & An, 2012; Ministry of Education, 2011). Four junior high school math teachers in Chinese confirmed to us that quadratic functions and symbolic–graphic combinations are complex and uninteresting for typical students. Therefore, it is necessary to integrate knowledge of quadratic functions into game play in a GIVRLE to not only help students grasp that knowledge but also improve their learning motivation. In addition, the game task in this study was designed based on daily living activities to help prevent game addiction.

2. Literature review

2.1. VRLE

A VRLE is a computer–simulated, 3D environment in which a learner can interact with the environment and experience telepresence. Many studies have explored the key characteristics of VRLE. In short, natural interaction and simulated presence have been the most frequently identified characteristics of VRLE in knowledge representation (Chang, Sheldon, Si, & Hand, 2012; El-Mounayri, Rogers, Fernandez, & Satterwhite, 2016; Jackson & Fagan, 2000; James et al., 2002; Lorenzo, Lledó, Pomares, & Roig, 2016; Mayrose, 2012; Orman, Price, & Russell, 2017; Roussou, Oliver, & Slater, 2006). Meanwhile, usability (Bourgonjon, Valcke, Soetaert, & Schellens, 2010) and playability (Järvinen, 2001), as well as similar notion such as likeability (Virvou & Katsionis, 2008) and enjoyment (Chen, Liao, Cheng, Yeh, & Chan, 2012), have been found to mainly contribute to user experience. Motivation (Lee et al., 2010) and other psychological factors (Saleh, Prakash, & Manton, 2014) have also been shown to facilitate learning in VRLE. Given these advantages, VRLEs have been widely examined in collaborative learning (e.g. Burton & Martin, 2010), active learning (e.g. James et al., 2002; Mayrose, 2012),conceptual learning (e.g. Limniou, Roberts, & Papadopoulos, 2008; Roussou et al., 2006), skill learning (e.g. El-Mounayri et al., 2016; Lorenzo et al., 2016; Orman et al., 2017), and science education (e.g. Minogue, Jones, Broadwell, & Oppewall, 2006). Unfortunately, few VRLE studies have been conducted for mathematics learning (Adamo-Villani, Carpenter, & Arns, 2006; Chen et al., 2012), especially for its difficult aspects. This partly have to do with the difficulty of combining complex mathematical ideas with enjoyable virtual reality environments.

2.2. GIVRLE for math learning

2.2.1. Game–based VRLE for math learning

A game–based VRLE integrates a VR–based learning environment with a VR–based game. Compared to VRLE, game–based VRLE showcases its advantages by providing challenges and enjoyment, which obviously boost learning motivation (Giannakos & Michail, 2013; Limniou et al., 2008; Liu, Rosenblum, Horton, & Kang, 2014; Maitem et al., 2012; Vogel, Greenwood-Ericksen, Cannon-Bowers, & Bowers, 2006; Xu & Ke, 2016). Compared to traditional classroom instruction, gamed–based VRLE has two promising characteristics: 1) a kind of active learning motivated by experience of challenge, enjoyment, and engagement, and 2) situated knowledge representation that facilitates knowledge acquisition. A number of studies have explored the value of game–based virtual learning environment in mathematic learning (e.g. Adamo-Villani et al., 2006; Chen et al., 2012; Giannakos & Michail, 2013; Ke, 2013; Pasqualotti & Freitas, 2002), but only several cases were conducted with game–based VRLEs. Kebritchi, Hirumi, and Bai (2010) examined the learning outcomes of a game–based math learning VRLE (DimensionM™) among high school students and found that the VRLE enhanced both math achievements and learning motivation. Maitem et al. (2012) examined a game–based VRLE (Math World) and confirmed its enhancement effect on learning gains and learning experience. To further examine the role of intrinsic integration between learning content and gameplay, Xu and Ke (2016) designed a gamed–based VRLE (Island of Pi) to address knowledge of fractions and proportions for elementary school students. Embedding the learning content in an adventure game task, they found that the balanced integration of learning content and gameplay enhanced user experience (e.g. playability, enjoyment). In light of such findings, more research is needed to further enhance game–based VRLEs.

2.2.2. Current issues in game–based VRLEs for math learning

Fully immersive displays, such as trackable head mounted display (HMD) and CAVE, provide the best experiences for both presence and interaction. However, to our knowledge, few studies explored the value of GIVRLE on learning outcomes, indicating a need for further research. One previous study conducted an immersive VRLE to teach deaf children sign–language mathematics (Adamo-Villani et al., 2006). Thought the high cost of devices has limited the application of game–based VRLEs, the problem is being resolved thanks to a number of leading technology companies. Consumer version of fully immersive HMDs are now available, such as Oculus Rift, HTC VIVE. At the same time, several excellent game–development platform, such as Unity, Worldviz, provide a variety of resources for building GIVRLEs. Fully immersive VRLE offer learners more acceptable experiences of presence, such that first–person experience and nonsymbolic interaction, support knowledge construction in activity bound to social and physical contexts.

The balance between entertainment and learning is another issue in game–based VRLEs. Though games can acquainted the children and adolescents with the use of computers, they can also give rise to the problem of game addiction (Griffiths, Kuss, & King, 2012; Mumtaz, 2001; Nansen, Chakraborty, Gibbs, Vetere, & Macdougall, 2012). To balance entertainment and learning, one possible solution is to combine existing learning theories with game design rationales via VR techniques (Young et al., 2012). The frequently used theories in educational games mainly consist of behaviorism, constructivism, and flow theory (e.g. Qian & Clark, 2016). While these theories elucidate the process of learning in a game, they fail to provide specific suggestions for how to differentially design educational and commercial games. In addition to existing theory, this study adopted the notion of life education (Tao, 1981) and that education is life (Dewey, 1916) as a guideline for task design in GIVRLE. Dewey's and Tao's theories elaborate on the relationship between education and life by emphasizing that learning takes place for life and in life; thus "teaching, learning and practice come together as one" in life. Therefore, educational games should be based on daily–life activities rather than purely intrinsic attractions (e.g. combat or fighting) as in commercial games. Most junior–high–level math knowledge could be linked to daily activities and integrated into game play. Although a daily–activity design might reduce the player's intrinsic motivation, it shows what knowledges is used in daily life. Moreover, a daily–activity design can mitigate concerns about game addiction. Second Life is one a successful example a daily–activity design (Faiola et al., 2013; Wilks & Jacka, 2013).

3. Methodology

All experimental procedures were approved by the review board of the researchers' institution. The methods followed the relevant guidelines and regulations. All participants signed informed consent forms approved by the Institutional Review Board. All participants were monetarily compensated.

3.1. Purpose of the study

This study aimed to test GIVRLE's usefulness for math learning. Questionnaires and experiments were conducted to test the usability, playability, and learning gains of a GIVRLE. This study's purpose can be delineated as follows:

a) Design a GIVRLE by intrinsically integrating learning content into gameplay based on a simulated daily activity task.
b) Examine the possible effect of the GIVRLE on improving math achievement and learning motivation.
c) Assess the user experience of the designed GIVRLE;
d) Evaluate the possibility of using the GIVRLE as a significant tool for solving math teaching difficulties in K–12.

In short, this study aimed to determine whether the GIVRLE can help students conduct self–direct learning.

3.2. Participants and apparatus

Participants Forty–three (20 male, 23 female) participants (in an intact class) were recruited from a rural middle school in Hebei Province, China, aged from 13 to 15. Three participants were excluded due to sickness. Another group of students (38 male, 22 female, aged 13–16) was recruited as a control group, which took the same pretest and posttest in math. The test and control groups were all seventh graders who had not learned about functions.

Apparatus The experiment was performed using a virtual reality system consisting of a head–mounted virtual reality helmet (HTC VIVE, HTC Corporation; 110° horizontal field of view, resolution 1080 × 1200 pixels per eye, refresh rate 90 Hz, integrated microphone, controller specs), an infrared tracking subsystem (3.5 m × 3.5 m tracking area, refresh rate 100 Hz), and an HP workstation (CPU E5-2667 3.20 GHz, RAM 56.0 GB, GPU NVIDIA Quadro K6000). The virtual reality environment (VRE) was presented in the head–mounted helmet, which was tracked by the infrared tracking subsystem. The software used in this study include 3dsmax 2012 for modeling and animation, and Unity3d for virtual reality scenes and interaction.

3.3. Materials

The materials used in this study consisted of questionnaires, surveys, learning achievement tests, and GIVRLE. The questionnaires were the Ten–Item Personality Inventory in China (TIPI–C), and the Igroup Presence Questionnaire (IPQ). The surveys included a learning motivation survey (LMS), and a Playability Survey (PS).

The TIPI–C is a type of self–rated big–five personality factor scale consisting of 10 pairs of adjectives with two items for each factor (Gosling, Rentfrow, & Swann, 2003; Lee, 2013). The scale was a 7–point Liker scale [Absolutely disagree (1), Uncertain (4), and Absolutely agree (7)] (see Appendix A). It has good reliability (α coefficients of five subscales, 0.60–0.67; criterion validities, 0.44– 0.58) Lee (2013). The scale was selected mainly because the students' time was limited.

The IPQ measures user experience in a virtual environment using seven–point Likert scales. The questionnaire contains 14 items in four dimensions (spatial presence, involvement, realism, general presence, see Schubert, Friedmann, & Regenbrecht, 2001), and has good reliability (α coefficients: 0.87).

Developed for this study, the LMS measures four items on five–point Likert scales [Strongly disagree (1), Uncentain (3), and Totally agree (5)] (see Table 1). Existing motivation questionnaires are mainly diagnostic tests. Therefore, as in prior studies (Huang & Liaw, 2011; Kebritchi et al., 2010), a pre– and posttest survey was used to measure the possible changes in learning motivation caused by the GIVRLE.

Also made for this study, the PS measures 10 items on seven–point Liker scales (see Appendix B). These items were selected based on four aspects of game playing: game task, game for learning, game for knowledge, and experience and operation. Järvinen (2001) suggested that playability is a tool for evaluating game quality, and has four elements: structure, function, audiovisual aspects,

Table 1. Mean scores and standard deviation (SD) of Learning Motivation Survey and pre- and posttests.

	Item	Pretest		Posttest	
		Mean	Std	Mean	Std
Math tests	5 multiple–choice questions about quadratic functions for either pretest or posttest	12.63	5.19	15.50	5.16
LMS (five–point Likert scales)	1. Are you interested in mathematics learning now?	3.98	1.00	4.68	0.63
	2. Do you think it's important to learn mathematics well now?	4.70	0.82	4.82	0.50
	3. Do you think learning mathematics is difficult now?	3.88	1.11	4.60	0.63
	4. Do you think mathematics can be applied to problem-solving in everyday life?	2.80	1.14	3.43	1.03

and social playability. This has been used to descript whether a game is worth playing. Despite its significant value, there is no standard scale for playability. The PS used in this study aimed to determine whether the game's playability was acceptable.

Pre– and postlearning tests To examine the effectiveness of the GIVRLE, five multiple–choice math questions were used to test the level of math achievements in quadratic function. To ensure content validity, these questions were selected by three math teachers in terms of typicality and moderate difficulty. For the experiment, five equivalent questions were selected for the pre– and postlearning tests (see Appendix C).

GIVRLE We built a virtual basketball court in a virtual park, see Figure 1. There are no basketball hoops but a special wall with grid lines on the court. Based on the wall and other objects, a shooting game was then designed.

The shooting game in the GIVRLE was called Crazy Pot. It combines a game scenarios with a help system and a reward scenario. In the shooting game scenario (see Figure 1), a shooting task is created on a court. On the wall, Cartesian coordinates are marked to provide location information. The two pots on the wall provide the coordinates of the target point, and the red or green launcher's position on the wall is marked as the starting position of the parabola. Tips are available from a "help spirit" appearing after three consecutive failures. By touching the "spirit", the player could see a short video that briefly illustrates how to win through computation. The content of the illustration in the short videos varies according to different checkpoints in the given game level. The bamboo basket on the sideline is used to collect objects dropped during the game. The reward scenario is experiencing the crane flying in the blue sky (see Figure 1).

3.4. Design

This study used a pretest–posttest experimental design. To help ensure validity, we used four steps to improve the design. First, we used a contrast group to reduce the possible repeat effect on the knowledge test. Two intact classes in the seventh grade were selected, and the class that the teacher gave more positive comments to was used as the control group. Second, multiple indicators were used to observe the consistent effect of the GIVRLE on learning. IPQ and PS were used to assess user experience, pre– and posttests were used to assess learning gains and learning motivation, and a personality questionnaire was employed to examine possible psychological factors. The test group received all of the tests while the control group completed two equivalent quadratic function tests within forty minutes. Third, an average–performing school was selected to avoid selection bias. The study was conducted in a rural junior high school that was ranked as an average–performing high school by the local society. The rural school was selected for two main reasons: 1) students in the school rarely took part in extracurricular tutorial classes, 2) the rural schools are considered potential recipients when considering unbalanced educational resources. Finally, no instructions related to the knowledge tests were included in the questionnaires, surveys, motivation tests, or the GIVRLE. All

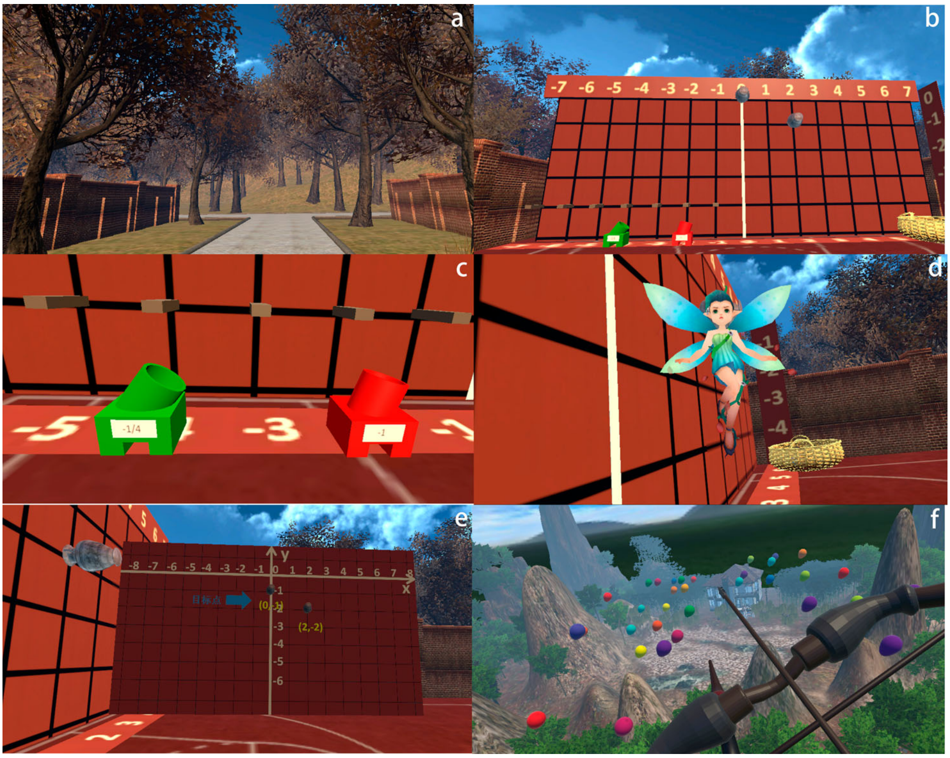

Figure 1. Scenarios used in the presented GIVRLE. (a: shows the entrance of Happy Park; b: the game scenarios of Crazy Pot; c: the red and green launcher; d: the "help spirit"; e: a help illustration; f: the reward scenario, experiencing the crane flying in the blue and shooting balloons while riding on a crane).

tips in the GIVRLE were given in instances of the failure in the game task, and no relationship to the tests or to classroom learning was mentioned.

Daily activity used in the current study is a basketball shooting task specified as four game levels for student players, in which each level address a knowledge point and results in total of four knowledge points: simple form (vertex on the origin coordinates), vertex form (vertex move along X axis), vertex form (vertex move along Y axis) and general form. Prior study shows that intrinsic integration of learning content and game play is required for intrinsic motivation (Habgood & Ainsworth, 2011; Virvou & Katsionis, 2008). The goal of the present study is to test the concept of daily–activity design in a GIVRLE as a way to help average students understand difficult and abstract learning content.

Game design The Crazy Pot game consists of a pot–shooting task, a help system and a reward system. There were two reasons for selecting a pot–shooting task. First, the graph of quadratic functions is a parabola similar to the trajectory of a flying rock. Thus, the trajectories of fly rocks in a pot–shooting task were used to simulate and demonstrate the properties of quadratic functions. Second, most students have daily life experiences similar to the game, so it was natural and easy to link complex quadratic function knowledge to visible and intelligible game tasks. To guide players to gradually learn the properties of quadratic functions gradually, the pot–shooting game was designed as a four–level game task according to quadratic function difficulty. For example, at level 1, the pots appear at the two points [(0, 0), (2, −1)] of the quadratic function ($y=-1/4x^2$) first and then at the two points [(0, 0), (1, −1)]. If a player shoots all four pots successfully, he or she advances to level 2. Similarly, the player will have to shoot four pots (two shots) at the positions of a quadratic function which has moved one unit to the left along the X–axis at level 2 ($y=-1/4(x-1)^2$), one unit along the Y–axis at level 3 ($y=-1/4x^2+1$), and one unit along both the X– and Y–axis at level 4 from the original function ($y=-1/4(x-1)^2+1$) (see Figure 3). In each level, the player either scores after shooting the pots on the wall twice or gets a chance to ask for help. The difficulty of launcher–location computation tends to increase with each level.

Feedback helps to improve learning (Charles, Charles, Mcneill, Bustard, & Black, 2011). To appropriately encourage players to use the help information, three consecutive failures automatically triggered a help procedure, where the "help spirit" pops up in front of the wall. The spirit first dances and then flies to an emerging screen on which an animation is played that briefly illustrates how to compute the correct launch location using quadratic function knowledge related to the level. The help system contains many illustrations showing how to apply quadratic function knowledge to the shooting task. As the number of failures increases, more detailed illustrations for the same pot location are provided. Considering that the users had not yet learned about quadratic functions, the conception of graphic–to–symbolic relation was just mentioned without further explanation. Therefore, the illustrations presented in the help system mainly focus on computing the launch location based on quadratic functions. For example, in level 1, an animated illustration shows how the trajectory of the flying rock can be viewed as a quadratic function. The simple form of the quadratic function is $y = ax^2$. By default, the launcher will hit two pots at level 1 (vertex on the origin coordinates). The player can calculate the value of "a" by substituting the coordinate points of the pot into the simple form of the quadratic function. If he or she fails to do this, a help illustration appears. In this test version, the game provides two launchers. There is a parameter on launcher that displays the launch angle, corresponding to the value of "a" in the function expression, so the player can compute and pick an appropriate launcher. Because the launcher always moves in the position of $y=-4$, the value of X can be obtained by substituting $y=-4$ into the formula. With the values of X and Y, the location of the transmitter can be known (see Figure 2).

A successful shot always leads to some treasures. When a user collects half of all the treasures, he or she gets to experience riding a crane in the sky, in addition to the gold chips. If a player passes all four levels, he or she obtains all the gold chips and can shoot balloons while riding on a crane. Although the game provides such external rewards, they are largely autonomous pursuits that create internal motivations for continuing the game task. During play, user can walk (in a 5 m x 5 m area) or move via teleportation in the scene. Interaction, such as ray casting and the handle operations of picking up an object, triggering the launcher and drawing the bow, were added to increase the playability of the game. Shooting game is a type of action game. Such a design was based on the hypothesis that most students with low learning motivation would like action game and would be interested in learning by doing.

3.5. Procedure

Students first completed LMS (pretest), TIPI–C and pre–experiment math test, in that order, and then listened to an introduction to the VR apparatus. Next, an experimenter helped with attaching the VR head gear. Students then logged on to the Crazy Pot game and appeared as a player in the game. After experiencing navigation via teleportation or walking in the game, they were instructed to start the game. During the game, students performed game tasks in terms of instructions given by the system. They have to pass all four levels in order. In each level, the player could either pass or try again with help from the "spirit". They could eventually pass all levels using the help illustrations based on quadratic functions. The flight experience reward would emerge after successfully passing level 2 and level 4. After passing all levels, the student completed post–experiment math test, LMS, IPQ and PS. Figure 3 shows the GIVRLE procedure. The whole experiment lasts about 35 min, with game taking about 20 min.

3.6. Data collection and analysis

Participants attended the experiment individually. The time and the scores (gold chips in the game) were automatically recorded by the system according to registration. Questionnaires and tests were

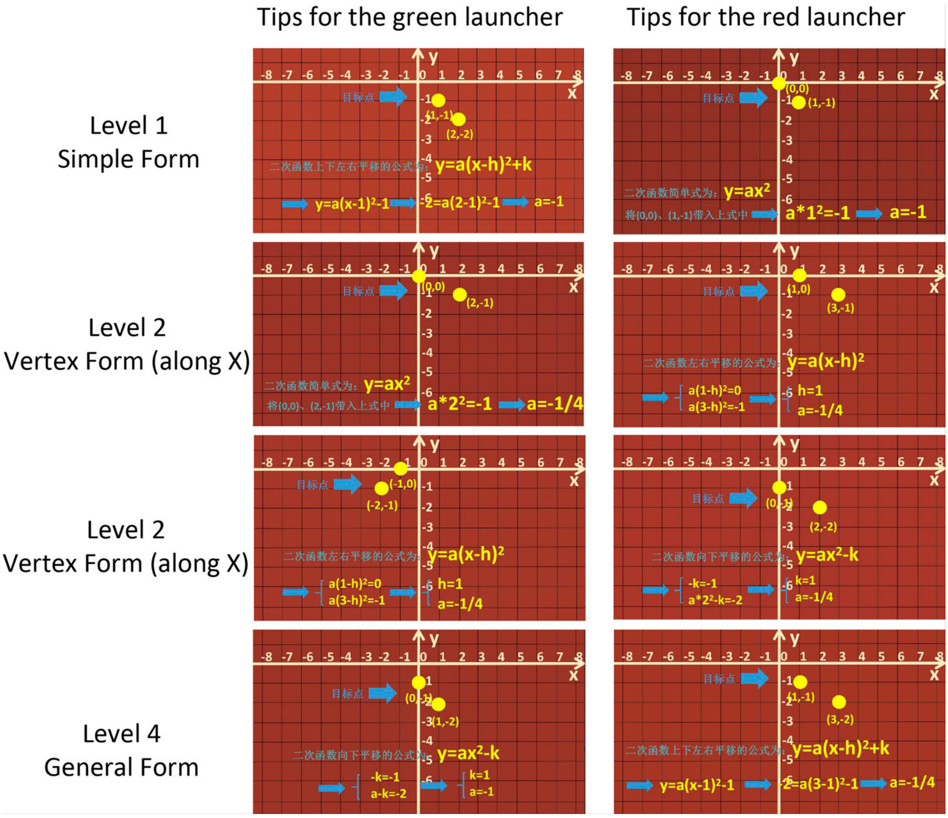

Figure 2. Knowledge architecture in the presented GIVRLE.

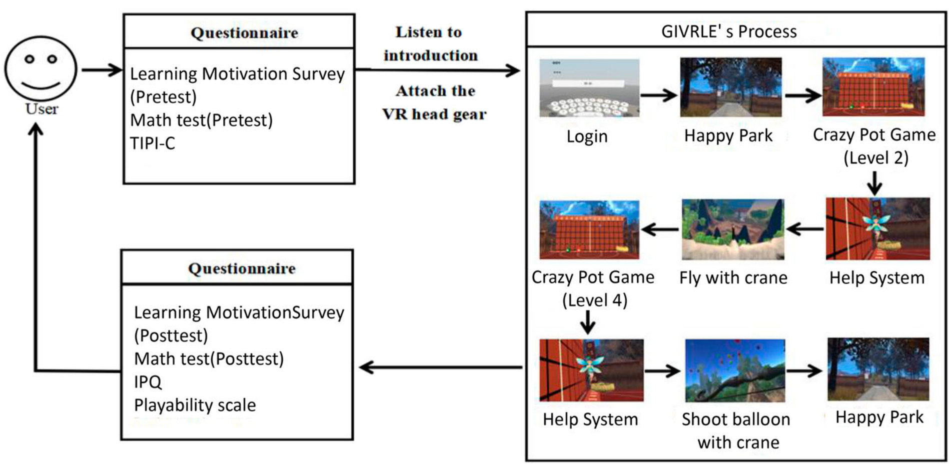

Figure 3. The procedure of this study.

marked and entered into a database. Participants in the control group just took math tests in class within 40 min. To help ensure validity, graduate students from other psychological studies served as experimenter, and the multiple–choice questions used in both of the quadratic function tests served to avoid marking bias. All data were collected in the classroom during self–study classes. Data were analyzed between the pre– and posttests, and the learning gains were compared between the test and control groups.

4. Results

4.1. Achievement tests

The math test scores of the test group participants showed a learning effect, in that the achievements on the posttests ($M = 15.50$, $SD = 5.16$, equal to 62%) were higher than those on the pretest ($M = 12.63$, $SD = 5.19$, equal to 50.52%), t (39) = −3.219, $p = 0.003$, $d = 0.56$. In the control group, no significant differences were found between the pretest ($M_{pretest} = 18.83$, $SD = 4.26$, equal to 71.68%) and posttests ($M_{posttest} = 17.92$, $SD = 4.63$, equal to 75.32%), t (59) = 1.170, $p = 0.247$, see Table 1. The results indicated that playing Crazy Pot was conducive to quadratic function learning. Although the control group performed better on the pretest, no significant improvements were found on the posttest. A comparison between the GIVRLE group and control group in the math pretest shows that the GIVRLE group had a better performance, suggesting that learning ability was not an issue in explaining the improvement on the math tests.

4.2. Learning motivation

The LMS indicated that the posttests scores ($M = 17.58$, $SD = 1.46$) were higher than the pretest scores ($M = 15.35$, $SD = 2.38$) (see Table 1). Analyses of t–tests showed that Crazy Pot can improve students' learning motivation, t (39) = −6.26, $p < 0.001$, $d = 1.13$.

4.3. IPQ scores

The students' IPQ scores indicated that the mean scores on all four dimensions were higher than 3 which is considered as a criterion for a good user experience with a VRLE (Schubert et al., 2001). The mean scores of each dimension are shown in Table 2.

4.4. Playability

The PS has four dimensions: game task, game for learning, game for knowledge, and experience and operation. The PS results indicated that the mean scores on all four dimensions were higher than 4 which is believed to indicate that the learning system has good playability and user satisfaction. Table 2 shows the mean scores for each dimension. Further analysis showed that the survey had acceptable reliability (0.456), and factor analysis indicated that four main factors explained about 70% of the total variance. The four factors obtained in factor analysis were not consistent with the proposed four dimensions, indicating that more work is needed to develop a playability scale.

Table 2. Mean scores and standard deviation (SD) of IPQ and PS.

	Dimensions	Mean	Std
IPQ (seven–point Likert scales)	Presence	4.85	1.63
	Spatial Presence	4.99	1.64
	Involvement	4.27	1.90
	Experienced Realism	3.73	2.01
PS (seven–point Likert scales)	Game Task	4.61	1.88
	Game for learning	5.57	3.26
	Game for knowledge	5.92	1.84
	Experience and Operation	5.59	2.59

Table 3. Correlations between personality factors and learning gains, LMS, PS and IPQ.

	Personality Factors	Openness	Neuroticism	Extraversion	Agreeableness	Conscientiousness
Math tests		0.042	−0.025	0.370*	0.093	−0.035
LMS		−0.050	−0.209	−0.131	−0.099	0.109
PS	Experience and Operation	0.151	−0.069	−0.067	0.097	−0.090
	Game task	−0.157	−0.037	−0.061	0.000	−0.221
	Game for knowledge	0.043	0.136	0.184	0.117	0.373*
	Game for learning	−0.061	0.170	−0.012	−0.012	0.115
	Total score	−0.004	0.097	0.002	0.074	0.071
IPQ	Involvement	0.054	0.200	0.036	0.245	0.029
	Experienced Realism	0.027	0.273	−0.096	0.175	−0.099
	Spatial Presence	0.186	0.206	−0.073	0.354*	−0.030
	Presence	0.009	0.190	0.006	0.415**	0.076
	Total score	0.103	0.306	−0.049	0.371*	−0.028

Note: * indicates a significant correlation at the level of 0.05
** indicates a significant correlation at the level of 0.01

4.5. Correlation analysis

Table 3 reports the results of the correlation analyses between personality factors and improved academic achievements. A significant correlation was found between extraversion and achievement improvement, indicating that the GIVRLE designed for this study is more suitable for extroverted students. It is easy to understand this finding when considering that an action game task was designed for the present GIVRLE. In addition, a significant correlation between PS and conscientiousness was obtained. It suggested that the design of the GIVRLE might be subject to carelessness.

5. Discussion

This study aimed to investigate whether a GIVRLE facilitate quadratic function learning in junior high school students who had never been taught such content. The results of math tests showed significant improvements in the posttest versus the pretest in test group but not the control group. A learning motivation survey also showed a significant enhancement of motivation for math learning in the test group. Since no traditional math instructions were incorporated in the GIVRLE, our hypothesis that playing the GIVRLE could facilitate complex knowledge learning was confirmed. More importantly, the GIVRLE not only implicitly boosted math learning but also explicitly improved player's learning motivation, showing an ability to help student conduct self–directed learning. This finding is in line with previous studies (Kebritchi et al., 2010; Maitem et al., 2012; Virvou & Katsionis, 2008; Xu & Ke, 2016). In the future, a GIVRLE could provide a new means of learning in which complicated knowledge learning occurs during game play, especially in K–12 education.

Daily–activity design is a promising way to build an acceptable GIVRLE. Using a daily activity task, an intrinsic and balanced content–gameplay integration in GIVRLE is feasible (Habgood & Ainsworth, 2011; Xu & Ke, 2016). Game tasks based on daily living activities not only reduce the possibility of game addiction but also effectively solve actual teaching problems. If we only focus on the attraction of a game, then edutainment could become another kind of commercial game, and design concept hinging on instinctive behaviors (e.g. combat, sex, and fighting) will return. However, if we aim to solve knotty problems in learning and teaching, then the sources of knowledge could be oriented in the right direction, as with the daily–activity design in the present study. To certain extent, balanced content–gameplay integration in GIVRLE is a process by which game designers find sources of knowledge. From the perspective of distributed cognition, knowledge acquisition occurs in a given situation via interaction between leaners and computerized co–learners (Dillenbourg & Self, 1992; Vvidis, 2002). Thus, learning in VRLE is a kind of situated learning (Huang & Liaw, 2011). Daily living activity is the most intelligible and available source of situated learning, which aligns with the notion that life is education (Dewey, 1916; Tao, 1981). Likewise, reviving the notion that "education is life" is conducive to solving the existing teaching problems.

Fully immersive VRLE and intrinsic integration between learning content and gameplay supported both learning outcomes and learners' experiences. In traditional class instruction, most students dislike abstract and complex knowledge, such resistance thus decreases their learning effects. In a GIVRLE, however, the fully immersive VRLE offers students a strong presence, while intrinsic integration design eliminates the unintelligible aspects of learning content. Consequently, the enjoyments experienced in a GIVRLE boosts learning gains. With the development of VR technology, fully immersive VR settings would not be an issue. Although daily activity is not so competitive compared to commercial game tasks (e.g. combat, fighting, adventure), it is a low–cost available subject for most teachers. We believe fully developed programing tool and VR engine could ultimately turn teachers into GIVRLE designers.

Finally, personalization is always the final obstacle when applying GIVRLE to solve teaching difficulties in K–12. The results of correlation analysis in the present study indicated that basketball shooting task is more suitable for extroverted students. It is easy to understand why extroverted students would like basketball shooting as a daily activity. Among existing studies, playability is also used to show all possible factors related to learning and learners' personal factors (Virvou & Katsionis, 2008). Playability is a developing conception that involved in personalization but essentially focuses on user experience. The personality questionnaire used in the current study was not a specialized test for learning style as well, but it did show learners' preferences for game subject. By taking learning style into consideration, a GIVRLE study could be expected to obtain better results. As a teaching assistant system, GIVRLE must be based on the intelligent classification of learner's learning styles in a virtual reality environment.

6. Limitations

The present GIVRLE was designed to help students understand those abstract and complex math knowledge before classroom learning, so we prioritized effectiveness to efficiency. Practically, it is necessary to compare playing–game to traditional instruction. In fact, we had built a simulated classroom prior to Crazy Pot, but the simulated classroom failed to facilitate quadratic function learning. Nevertheless, the comparisons between Crazy Pot and traditional classroom instructions will certainly promote our understanding of GIVRLE. In addition, the small sample was another limitation of this study. The program used in this study was a single–user test version. It was difficult to collect a large sample data due to the expensive devices and the limited classroom space. We believe all these problems will be resolved soon later.

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Notes on contributors

Aili SHI is a master degree candidate for user experience in College of Psychology, Capital Normal University. She is interested in human–computer interaction and assessment of user experience in virtual reality learning environment.

Yamin WANG is the founding director of Capital Normal University's Virtual Simulation Center for Experimental Teaching of Psychology and a cognitive associate professor in Beijing Key Lab of Learning and Cognition. He received the Ph.D. degree in cognitive psychology from Institute of Psychology in Chinese Academy of Science in 2007. His research interests include situated cognition, virtual reality learning environment, VR-based emotion induction, ubiquitous learning systems. And now his research focuses on intelligent assessment of human performance in virtual reality environment with the technique of VR-based eye tracking.

Nan DIN got his master degree in engineering psychology in 2017 from College of Psychology, Capital Normal University. He is now a design engineer of intelligent education system.

ORCID

Yamin Wang http://orcid.org/0000-0001-6059-6553

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Appendices

Appendix A

Playability survey

1. You think you can play in the game you just experienced.

Short time 1 2 3 4 5 6 7 Long time.

2. You think the operation in the game is.

Easy 1 2 3 4 5 6 7 Difficulty

3. What do you think the checkpoint in the game

Easy 1 2 3 4 5 6 7 Difficulty

4. What do you think of the task in the game

Boring 1 2 3 4 5 6 7 interesting

5. You think playing the game is compared to class

Like 1 2 3 4 5 6 7 Same

6. What time do you think the game is suitable for

Leisure time 1 2 3 4 5 6 7 Class time

7. Do you think the game reflects the use of mathematical knowledge

No 1 2 3 4 5 6 7 Yes

8. Do you think the scene is more game oriented or mathematical

Mathematical 1 2 3 4 5 6 7 Game

9. In this way, is it helpful to your mathematic learning

NO 1 2 3 4 5 6 7 Yes

10. Do you like to join this form in future studies

Dislike 1 2 3 4 5 6 7 Like

Appendix B

Pretest

1. The image of the quadratic function approximates ( ).

A. Hyperbola B. Straight line C. Parabola D. Curve

2. The quadratic function expression is $y=-(x-1)^2$, which of the following points is on the graph( ).

A. (0, 0) B. (0, −1) C. (2, 1) D. (1, 1)

3. It is known that the (0, 0) point and the (2,−1) point are on the quadratic function graph, then which of the following points is also on the quadratic function graph( ).

A. (−2, −1) B. (4, −1) C. (−2, 1) D. (−4, −1)

4. It is known that the quadratic function graph passes through the (1,0) point and the (3,−1) point, then the quadratic function expression is( ).

A. $y=-\frac{1}{4}(x-1)^2$ B. $y=-\frac{1}{4}(x+1)^2$ C. $y=\frac{1}{4}(x+1)^2$ D. $y=\frac{1}{4}(x-1)^2$

5. The quadratic function graph passes through the (0,−1) point, (2,−2) point, and when y=−5, the value of x is( ).

A. −1 B. −2 C. −3 D. −4

Posttest

1. What can be seen as a quadratic function graph in life? ( )

A. Basketball throws B. Waterfalls pop up from top to bottom C. Car wheel rotation D. Rocket liftoff

2. The quadratic function expression is $y=-(x-1)^2$, which of the following points is on the graph. ( )

A. (0, 0) B. (0, −1) C. 2, 1) D. (1, 0)

3. It is known that the (0, 0) point and the (1, −1) point are on the quadratic function graph , then which of the following points is also on the quadratic function graph . ( )

A. (−1, −1) B. (−1, 1) C.(−2, 1) D.(2, −1)

4. It is known that the quadratic function graph passes through the (1,0) point and the (2,−1) point, then the quadratic function expression is( ).

A. $y=-(x-1)^2$ B. $y=-(x+1)^2$ C. $y=(x+1)^2$ D. $y=(x-1)^2$

5. The quadratic function graph passes through the (0,−1) point, (1,−2) point, and when y=−5, the value of x is( ).

A. −1 B. −2 C. −3 D. −4