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Effective Learning Design of Game-Based 3D Virtual Language Learning Environments for Special Education Students

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ABSTRACT

This current study aimed at creating a 3D virtual environment on Second Life particularly for special education students to enhance their first language, Mandarin, learning in vocabulary and sentence structures. Four students aged between 8 and 9 participated in this research. In addition to their inherent disabilities (mild autism spectrum disorder, attention-deficit hyperactivity disorder, or mild mental retardation), all the four participants suffer from delayed language development. The purpose of the 3-month study was therefore to establish a platform enhancing their learning of Mandarin Chinese. A design-based qualitative design was adopted in this study. The collected data included in-class observation, video clips of learning process, and post-study interviews with the four disabled children. Additionally, parents' comments on their children's oral expression skills at home were also collected. Through a two-cycle investigation, this research proposed six categories of Human-computer interface (HCI) design principles for using virtual worlds to enhance special education students' Mandarin learning. In addition, both the interview results and the parents' comments confirmed the effects of using this platform for special education students' learning.

Keywords

3D virtual environment, Second Life, Speech delay, Special education students, Design-based research

Introduction

Linguistic communication skills (LCS) are very important to human daily life. It is especially essential for children's development because it is highly relevant to their social, emotional, and learning foundation. For ordinary children, to acquire their first language (L1) through daily activities is usually not a problem (Owens, 2008), while for children with disability, their L1 acquisition is not as natural. In fact, many children with disabilities are often comorbid with language delay or language disorders (Reed, 2014). If they are unable to obtain substantial learning support through early intervention, the sequential problems in academic achievement and social skills will cause severe emotional and behavioral problems which will hinder children from successful employment after graduation and ultimately become the social issues that may need to be dealt with at high social costs (Bercow, 2008).

Thus, the LCS problems encountered by children with disabilities should be diagnosed and dealt with as early as possible. Obviously, it is both a pedagogical and a social issue if not addressed properly. For a long time, multiple teaching approaches and instruments have been used to enhance the LCS of children with disabilities. In most circumstances, traditional teaching aids, such as paper-based pictures, building blocks, word cards, and colorful charts, are used. Today, the preparation of the abovementioned teaching aids requires a high cost of manpower and material resources. What's more challenging is that students require individualized instruction and that teachers should maintain students' focus and interest. In recent years, multimedia and interactive eBooks are attracting special education teachers' attention due to the multimodal input available in those advanced technical tools (Birmingham & Davies, 2001). In addition to the abovementioned computer-assisted language learning materials, 3D virtual worlds are also attracting educators' attention in the area of special education. For example, Gilberta, Murphya, Kruegerb, Ludwigb, and Efrona (2013) investigated how 3D virtual contexts would benefit disabled learners' mental and social relationship. A total of 61 participants with different kinds of disabilities were involved in their study. After the 3-month long involvement, the researchers confirmed that the participants were benefited from the activities in the 3D virtual contexts in terms of several affective constructs, such as reduced depression, anxiety, and loneliness, and enhanced positive affection of living satisfaction. Additionally, the capability of enhancing students' skills to obtain actively immersive and social experience gradually makes 3D virtual worlds an important research topic in special education in recent years. Standen and Brown (2005) viewed virtual worlds as a multifunctional special education tool. They can be used to intervene special education students' learning to improve and evaluate their independent living skills and cognitive abilities. Additionally, Stendal, Balandin, and Molka-Danielsen (2011) argued that 3D virtual worlds, such as Second Life, have the potential to tackle the challenge faced by people with a lifelong disability in maintaining friendships and staying included in communities, and therefore consequently reduce their lonely feelings caused by their inherent physical disability. In fact, several studies on using 3D virtual worlds for special education have revealed the high potential for facilitating people with disabilities to develop essential skills for their daily life (Mitchell, Parsons, & Leonard, 2006; Standen & Brown, 2005), to improve their self-esteem, confidence (Weiss, Bialik, & Kizony, 2003) and mental health (Gorrindo & Groves, 2009), and to enhance their cognitive abilities including attention, spatial perception, and reaction abilities (Parsons, Silva, Pair, & Rizzo, 2008).

While studies on using 3D virtual worlds in special education have largely confirmed their potential for enhancing special education children's learning, most of them focused on training children to acquire essential skills for their daily life, such as shopping in a shopping mall (Erez, Weiss, Kinozy, & Rand, 2013), undertaking physical training (Weiss, Bialik & Kizony, 2003), understanding transportation rules (Bart, Katz, Weiss, & Josman, 2008), and engaging in social interaction (Gilberta et al., 2013). Little research has been reported with regard to enhancing those children's LCS. Furthermore, some researchers did not agree that virtual learning environments (VLE) are ready for the use in special education (Habib et al., 2012; White, Fitzpatrick, & McAllister, 2008). For example, Habib and her colleagues (Habib et al., 2012) argued that some obstacles existing in VLE would hinder disabled students from being benefited from the environment. What concerns the researchers the most is the issue of human-computer interface (HCI).

HCI is user-centered and accentuates the need for designing the e-learning environment before focusing on the computing itself (Muzio & Serra, 2001). Likewise, HCI focuses on satisfying the needs of users, the general users and especially those with disabilities. In addition to the general guidelines for designing and structuring accessing e-learning applications, such as the Web Content Accessibility Guidelines (Kelly, Phipps, & Sloan, 2005), some additional guidelines should be considered when designing an e-learning environment for users with special needs (Debevc, Verlič, Kosec, & Stjepanovič, 2007). Regarding the research relevant to HCI for disabled users, most focuses on the design of a web-based learning environment. However, very few studies have focused on the principles of HCI design of 3D virtual worlds for enhancing special education students' LCS development. Despite this, 3D virtual worlds, such as Second Life, have proved to be an effective environment for enhancing learners' acquisition of a second language (L2) (Lan, 2014; Lan, 2015). It is therefore worthy of an investigation into the potential of learning in a 3D virtual world in promoting the LCS development of children with disabilities. Thus, how to design a barrier-free learning environment is a critical issue when considering a 3D virtual environment as a learning facilitator for children with disabilities.

In summary, 3D virtual technology has great potential in creating an immersive and socially interactive environment for children with disabilities to learn daily living skills and in rehabilitating their physical and mental disorders. However, the benefits of using 3D virtual worlds to the LCS learning of children with disabilities are still under investigation. Therefore, this study aims at developing a barrier-free learning environment in a 3D virtual world to enhance special education children's LCS development. To achieve the abovementioned research goals, two research questions will be answered: (1) what are the principles of designing a 3D virtual environment for disabled children's L1 learning? (2) What are the effects of learning L1 in 3D virtual environments on disabled children's LCS development as perceived by the participating children and their parents?

Method

Participants

The participants were four disabled children who were diagnosed with mild autism spectrum disorder (ASD), mild mental retardation (MR), or attention-deficit hyperactivity disorder (ADHD), and all were comorbid with language delay or language disorders at an elementary school in northern Taiwan. Three of them were first graders and one was second. Table 1 lists a brief description of the four children, including their 1) categories of disability, 2) intelligence quotient (IQ), which was evaluated by the revision of the Wechsler preschool and primary scale of intelligence (WPPSI-R), and 3) their L1, Mandarin Chinese, ability which was evaluated by the receptive and expressive vocabulary test (REVT) before the study. Additionally, the results of REVT are represented by percentile rank (PR).

Table 1. The four disabled children's individual information

Participants	Categories of Disability	IQ	L1 abilities (PR)
A	ASD	95	4
B	ADHD	93	16
C	ADHD	87	7
D	mild MR	57	3

Table 1 suggests that the participants’ L1 abilities (PRs from 3-16) were far behind those of the non-disabled students of the same age. The diagnosis reports of each child reveal that describing daily life was the L1 ability that these children most urgently needed. In addition to the low L1 abilities, the very short attention span of the four disabled children also negatively influenced their social relationship and learning behaviors. In short, the comorbid of the delayed language development and their inherent disabilities usually made them fail in social interaction and academic achievements at school.

Research design

The current study adopted a design-based research (DBR) design. Two cycles of experiment lasting for 7 months were conducted to refine the 3D virtual contexts to meet the learning needs of the four participating children. Multiple qualitative data, including in-class observation which focused on the participants’ classroom behaviors, video data which recorded the learning process of each individual child, and interviews with both the four children and their parents, were collected and analyzed during the study.

The data of the in-class observation and the record of the learning process were analyzed and discussed among the participating teacher and the research team of seven people [two technology-enhanced language learning (TELL) researchers and five 3D engineers] soon after the completion of each lesson. The findings were then used to refine the design of the latter lessons. Additionally, the interview data were transcribed by the participating teacher and were checked by another special education teacher to confirm the exactitude of the transcription.

Instruments

Platform

The 3D virtual learning contexts on Second Life were developed by the authors. A total of eight contexts related to children’s daily living experience were created: a kitchen and a dining room in a house, a convenience store, a playground, a health center at a school, a zoo, a shopping mall, a traditional market, a night market, and public transportation. The virtual contexts are composed of embedded objects that can be found and events that can occur in each scene. In addition to the static contexts and learning contents, a game-based scheme was created to deliver the learning materials via joyful activities. The basic game factors included content-based feedback, challenge-passing, adventure exploration, and joyful rewards. Therefore, the participants were able to do self-directed learning by playing and to obtain real time feedback given by the learning platform.

Figure 1 shows two of the virtual contexts used in the study. The left one is a snapshot of one corner in a convenience store. The participants can learn to name the goods and say the essential sentences while looking for and purchasing items. In addition, the right one is a health center at a school. The participants can learn the objects’ names in the health center, and the sentences to describe their physical conditions. Moreover, each virtual object is interactive, i.e., the participants can click them and hear and learn the pronunciation and the description of the clicked items.

Figure 1. A convenience store (left) and a health center (right)

Learning design

A total of eight lessons designed by the authors were used in the study. Each lesson was implemented in a virtual context by embedding the learning materials in the virtual environment. Additionally, the learning materials of all the lessons which matched the contexts were embedded. For example, the goods that can usually be found in a convenience store were placed in a virtual store for the participants to explore and learn the names of the goods. Besides, each lesson is composed of four learning rounds: basic vocabulary learning (labeling), advanced vocabulary learning (categorizing, defining, and reasoning), sentence pattern practicing, and reviewing.

Interview questionnaire

The interview questionnaire was developed to understand both the four children's attitudes towards being involved in the proposed learning activities in 3D virtual worlds and their perceptions of the effects of learning in such an environment on their LCS development. They were asked a total of 15 4-point Likert questions which were classified into 4 dimensions: satisfaction (4 items) focusing on the children's motivation, interests, and joy when learning by playing in the virtual contexts; usefulness (6 items) focusing on the children's perceptions of the benefits from learning in the proposed contexts in terms of their LCS development; ease of use (2 items) asking the children whether the proposed environments are easy to use; and authenticity (3 items) asking them whether learning in the virtual worlds feels real. Moreover, in order to more concretely know how the children benefited from participating in learning in the 3D virtual environments, after they answered each question, the children were also asked to elaborate on their answers with reasons.

Appendix A is the English translation of the questionnaire. Its original version is in Chinse and can be found at https://drive.google.com/file/d/1ubgKS_qp03dVuweOJPmeprDUg-fzyiZh/view.

Procedure

Figure 2 shows the procedure of the study. As shown in Figure 2, Cycle 1 started with a needs analysis in which the research team consisting of a special education teacher, two TELL researchers, and five 3D engineers met regularly to understand disabled students' learning needs. After the learning needs were confirmed, three lessons and the corresponding 3D contexts were developed. Before the first cycle of trial, the children received training on basic SL operations which included how to move their avatars in SL, how to interact with the virtual objects by clicking, and how to listen to the questions posed by the system and to answer them by taking the correct actions.

Afterwards, the four students learned the three lessons by logging in the 3D virtual worlds and engaging in the game-based and self-directed activities. In each lesson, the special education teacher first provided the learners with essential explanations of the learning rules and the exploration targets, and then the four participants learned by playing individually. They worked on their own most of the time while the teacher and one researcher stood by offering guidance only whenever the students called out for help, especially for technical support. Additionally, all the learning processes were recorded by four cameras (one for each child) and a screen recorder installed in each computer. The in-class observation and videos were then analyzed to identify both the advantages and the areas for improvement of the proposed 3D virtual learning contexts and activities. All the analysis results served as the refining foundation for the second cycle.

After reflecting on the learning activities and 3D contexts, five more lessons and the corresponding 3D virtual contexts were developed based on the data analysis results of Cycle 1. Then, the four children started to learn the five new lessons by doing similar activities to those in the previous cycle, i.e., learning by playing individually. All the learning processes were observed and recorded as in Cycle 1. Following this, all the children were interviewed. Additionally, during Cycle 2, the parents' comments on their children's LCS at home were collected with a semi-structured questionnaire when they visited their children's special education teacher and were analyzed. The questionnaire can be found at https://drive.google.com/file/d/1nM43j_DdPd-H26fe8Z8-l1DfWZPdJxFE/view. Finally, the HCI designing suggestions for developing 3D virtual worlds to enhance disabled children's LCS were proposed based on the reflection and observation data analysis results.

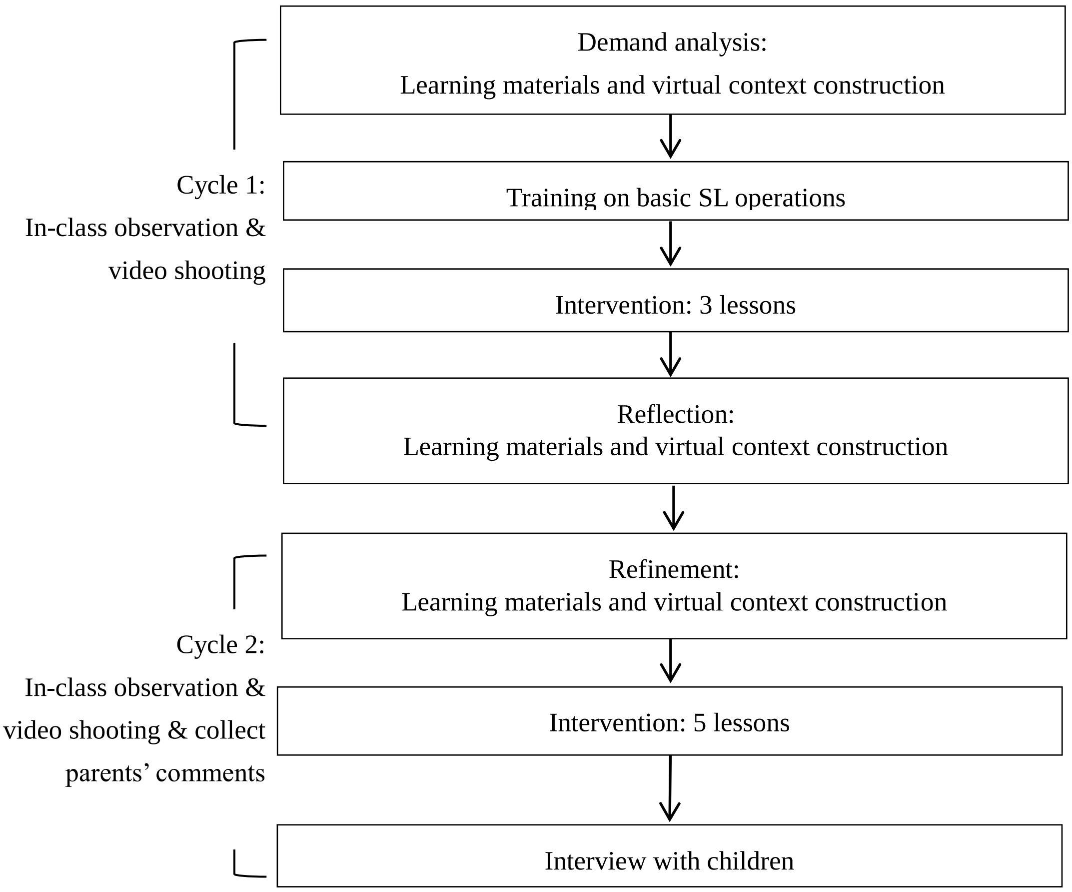

Figure 2. Procedure of the study

Results and discussion

The results of this study described below include two parts for answering the two research questions about (1) the design principles of 3D Learning Environments and HCI for children with disabilities, and (2) the effects of learning in 3D virtual environments on disabled children's LCS development as perceived by both learners and parents.

The design principles of 3d learning environments and HCI for children with disabilities

The principles for designing the HCI of a 3D virtual environment for enhancing disabled children's LCS learning proposed here were obtained by synthesizing the two-cycle results of in-class observation and video analysis. One copy of the observation notes for Unit 1, the kitchen and the dining room, can be found at https://drive.google.com/file/d/1LR5jLjIgvsoy_3JZG50Z0UAcig8FNDa-/view?usp=drivesdk. The principles can be classified into six categories as described below.

The levels of challenge and learning contents

When deciding on the levels of challenges and the amount of learning contents in. the 3D virtual environment for children with special needs, their short attention span for learning should be taken into consideration. It was found that there should be fewer learning materials and fewer test items embedded in each virtual context for students with disabilities in comparison with regular children, no more than six items. At the beginning, 10-12 question-based learning items were included in each round of a lesson. However, it was found that after answering 6 questions, the participants lost their attention and were easily distracted by the surroundings, such as the kids walking outside the classroom.

Additionally, the participating children suffer from different disabilities; thus, not only the problem of attention-deficit, but also the difference in their capabilities to learn should be taken into account. For this reason, the learning materials should cover language skills in different levels for different disabled children. For example, there are 4 rounds of challenges in each lesson in this study with round 1 being the simplest, and round 4 the most difficult. Additionally, round 1 targets at the simplest language skill, i.e., naming objects, while the other rounds with more difficult learning materials matched children's other learning abilities. It was found that Child D (mild MR) was able to learn the very basic skills such as naming a toy or the objects in the health center while the more advanced skills (e.g., reasoning and grouping) would be too difficult for her. However, the others with an average IQ enjoyed conquering all the learning challenges and gained satisfaction although they suffer from different disabilities (either ASD or ADHD). It was also found that the increasing difficulty of challenges in different rounds helped keep their learning interest and concentration on the learning tasks. For example, the most cheerful finding is that Child B (ADHD), who used to take medicine before coming to classes to help him concentrate on learning no longer needed to take medicine since halfway of the study. In fact, all the 4 children behaved similarly in attention extension. It was found that the time they were able to concentrate on learning was longer and longer as the study progressed.

Based on the abovementioned findings, three guidelines are provided below for effective learning design in a 3D virtual environment for children with disabilities.

- The number of challenge levels in each lesson should be limited, and four is suggested based on the findings of the current study.
- The number of the question-based learning items in each challenge level should be limited too, and a number of 5 or 6 is suggested due to children's short attention span.
- The degree of difficulty should gradually be increased to meet the different learning capabilities of individual children as well as to maintain their attention and interest. Even for a much-delayed learner like Child D, the difficulty level of a learning task should be gradually increased, at a rate and degree suitable for his/her learning capabilities.

The 3D operation functions

The SL system provided different avatar operation functions, such as walk, run, fly, sit, and wear. They do not present a high level of cognitive load to ordinary users as beginner players. However, it was found that if all the common functions provided by SL are enabled at the start, it would hinder disabled children from successfully accomplishing the assigned missions. For example, at the beginning of the study, they loved to fly but they easily got lost in the environments and consequently stopped doing the learning tasks. Regarding the functions for social interaction, it was found that both functions, text and voice, should be carefully controlled. To type words via the text chat function is not possible for those children because of their very limited Mandarin skills. Instead, voice chat can be used for social interaction. But it was later found that voice chat is the main source of distraction for those disabled students. At the beginning, when they found that they could hear their own and others' voices, they began to make noises, laugh and totally lose attention to learning activities.

It is worth noting that, however, if aural interaction is necessary for carrying out the assigned tasks, the voice chat function can be enabled a while later to avoid the disadvantages identified at the earlier stage because the attention period of those children had extended due to their experience in learning in the virtual worlds.

In addition to voice chat, the background sound/music or sound effects of operation functions are also the sources of distraction for disabled children. It was found that some children were very sensitive to certain sounds. For example, Child D (mild MR) was always frightened when she heard the sound of teleport. Additionally, Children A (ASD) and B (ADHD) were very sensitive to the peak sounds of the whale in the zoo (lesson 4), even though they were used to it during later lessons. On the other hand, Child C (ADHD) was always attracted by the "dadada" sound from the background.

Based on the findings described above, four guidelines are suggested below for the design and use of 3D operation functions.

- The available avatar operations in 3D virtual worlds should be minimal. At the early stage, some fast avatar moving functions should be disabled (e.g., run, fly and teleport), while only the very basic functions, such as walk, should be allowed to be used. As students' experience in learning in 3D virtual worlds increases, more operation functions can be unlocked for disabled children.
- Some avatar-object interaction functions, such as "sit" and "wear," should be locked for disabled learners at the early stage and be made available only when needed at a later stage.

- The voice chat function should be disabled at the start of the learning activity and enabled as needed in a later stage when children are used to learning in 3D virtual worlds.
- Background music/sound in the 3D worlds should be minimized and adjusted carefully to a comfortable level for children with disabilities.

The interactive 3D virtual objects

Because disabled children need more learning supports than do ordinary children as described in the Introduction section, a self-directed learning environment with timely feedback and learning guides is very important and useful for practical special education settings. Therefore, self-directed learning was emphasized in the study; most of the 3D objects in the virtual worlds are interactive. All the embedded learning contents can easily be accessed by a simple click. At the beginning, the classroom observation data demonstrated that the disabled children were unable to smoothly control the mouse to click the virtual objects (lessons 1 and 2). Therefore, at the beginning a sticker was stuck on the mouse to show the children which part of the mouse should be clicked, and this method was a helpful scaffold for those children to use the mouse to select the virtual objects. However, from lesson 3 onwards, none of the children needed to look for and follow the sticker while completing the learning tasks. In order to help the children successfully and correctly click the virtual objects, in addition to a sticker on a mouse, the positions of the virtual objects and their trigger areas should also be taken into careful consideration when placing the objects in the virtual worlds. If the objects were vertically placed, rather than horizontally, it would be easier for disabled children to click because we found that the occurrences of wrong-clicks were high when the objects were horizontally placed. In addition, the objects should also be placed with a certain amount of distance away from one another to lower the chance of mis-triggering. According to what was found from the video recording of the learning process, a too small trigger area embedded in an object will lead to missing or delayed feedback on children's clicks during the learning process. For example, in Lesson 3 "A health center at a school," a click on a single OK bandage cannot be easily done for the disabled children. Consequently, they will be confused about their learning. After enlarging the trigger area to cover a whole box of OK bandage, the problem was successfully solved. Therefore, the trigger area of an object should be large enough and should cover the entire object to guarantee that it can be triggered from any angles.

Furthermore, the unnecessary information about the inherent features of virtual objects, such as "You have no privilege to purchase this," should be disabled and should not pop out when the objects are clicked. The data from our video recordings of the sessions show that unnecessary information could easily distract their attention. Such information is usually in English, a language that they were unfamiliar with so they would usually spend much time on and got stuck with it, thinking that it was also a part of the learning material.

According to the findings described above, three guidelines are given below.

- The trigger area should cover the entire object. It can be triggered from different angles.
- Placing different objects vertically is better than doing it horizontally. If different objects should be placed horizontally, they should not be placed too close to one another.
- All the unnecessary functions or information embedded in any objects should be disabled and should not pop out when the objects are clicked.

Scene design

According to the children's diagnosis reports as described in the section of Participants, the scene design in the study should follow children's daily life experience so that it would be easier for them to transfer what they have learned in 3D virtual worlds to real life. For example, the traffic lights on the two sides of a road should be synchronized (Lesson 8). During the first trial, the traffic lights were not flashing synchronously on the two sides so the children were very confused and did not know when to cross the road. After modifying the control scheme of the traffic lights, they enjoyed crossing the road but noticed that nothing would happen even if they disobeyed the traffic rules. To ensure the children's awareness of traffic safety, the teacher then reminded them of the importance of obeying the traffic rules even though they were in virtual worlds. It was found that all the children started to observe the traffic rules after the teacher's reminder. Similar to the traffic issue, some places, such as the staff office in a post office (Lesson 8), were not allowed to enter without permission in the real world. However, in the virtual worlds, they could enter freely. Again, they were reminded of the rules applied in the real world. It was great to see that they were able to remember what the teacher had said and stopped violating the exploration rules.

In addition to the contexts, the arrangement of objects in the contexts was also important. It was found that the children loved to play with certain objects, such as a seesaw or a swing (Lesson 3) which offered hands-on interaction. At first, they were placed outside the exploration context of Lesson 2 (in a convenience store); it was found that children did not move on completing the tasks because they found those objects a great fun to play with their peers. Their attention was totally distracted away from the learning process. To deal with the problem, those fun objects were placed away from the current learning area. They were also told that they were allowed to play with them only if they successfully carried out the assigned mission. Two guidelines of HCI and scene design are given below according to the abovementioned findings.

- The design of the scenes should follow children's daily life experience so that it would be easier for them to transfer what they have learned in 3D virtual worlds to real life and vice versa.
- Objects that easily divert children's attention from completing learning tasks should be placed outside the learning area (on the exploration path). It is better to arrange another area to keep them and to be used as rewards.

Navigation

In traditional settings, disabled children are heavily dependent on teachers' reminders and orders to continue their learning process as described in the Introduction section. In the proposed self-directed learning environment in the current study, therefore, the embedded navigation scheme then becomes very important. It was found that without clear learning steps on the screen, those children were unable to smoothly advance from one challenge level to the next. For example, in the first three lessons (in Cycle 1), the children spent a lot of time on clicking here and there or asking teachers how many questions were left to answer. The teacher was busy keeping them engaged in completing the learning missions. To deal with this problem, reminding signs were added on the screen to inform the children which round they were in and how many target objects were left for learning (see Figure 3). By doing so, the frequency of distraction significantly decreased.

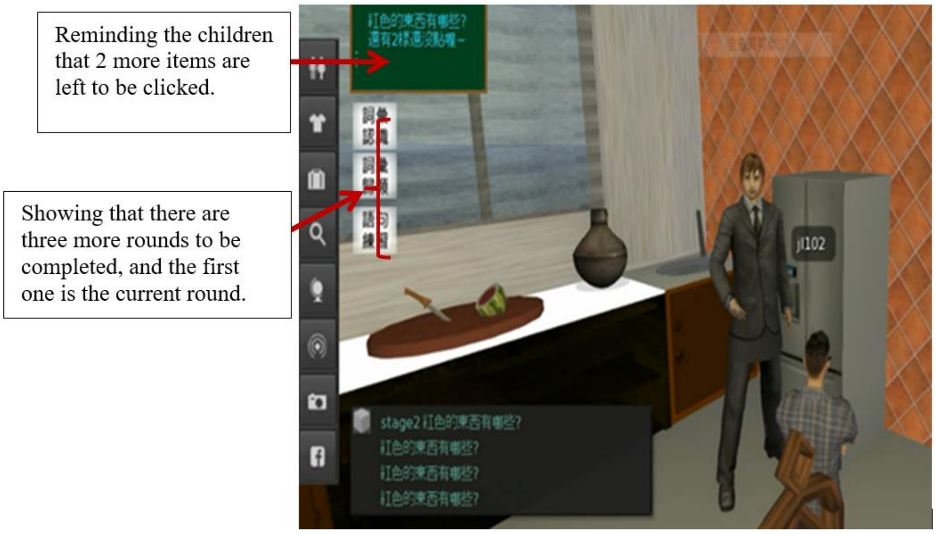

Figure 3. The reminders used for guiding the children in their learning process

In addition, at the beginning, because of the lack of knowledge in Chinese characters, some children were unable to read the reminders. Therefore, both textual and aural information was provided and the children were allowed to choose the one they preferred. Besides, it was found that sometimes the children could not remember or comprehend the information if it is played only one time. Multiple chances are needed for some children. Thus, the function of re-play or re-listen was added. Based on the abovementioned findings, two guidelines are given below in terms of an effective navigation design.

- The reminders showing the remaining learning missions and the current status are needed in helping disabled children progress more smoothly in the 3D virtual worlds.
- It is necessary to provide disabled children with the options to choose aural or textual information. The re-play function is also necessary for those children to re-listen or re-read the information or tasks.

Game functions

The game functions provided in the proposed system are proved to be essential for motivating and engaging the children. Sometimes, when Child B (ADHD), completed all the missions earlier than the others, he would visit and stay in the other environments created by the other players rather than the researchers. But soon he stayed there and felt bored. He explained that the environments he visited additionally were not fun because there was nothing left he could do except wandering. In fact, what Child B described is the common features of environments or scenes in Second Life in which no specific interactive activities are available for them. He said he loved the games in the proposed environments they used in the study. Additionally, in order to guarantee a smooth learning process, only the questions of the first level had to be answered one by one because they were basic in each lesson. The other three levels, Levels two to four, can be done without the completion of the former levels. While observing those children playing, it was found that Child D (mild MR) preferred completing sequential learning levels by answering one question after another. However, another child, Child B, preferred completing different learning levels without a particular order after his experience in learning in the virtual world increased.

In addition to the level structure (sequential or parallel), feedback is another point that is needed to be refined for disabled children's learning. It was found that both aural and textual feedback can easily distract children's attention from learning if too much information is given. After many trials, it was found that the symbol "O" meaning "correct" and the symbol "X" meaning "wrong" are better than the long aural or textual descriptions. The simplified message not only helps the students correct their mistakes but also provides them with timely feedback to help them concentrate on the learning process.

Reward is another factor to be considered in game-based learning. It was found that learning by playing in the virtual contexts is one kind of reward that those children love. For example, Child B (ADHD) was unwilling to help his peers before his involvement in the study. But after participating in this study, he became a friendlier child to others than he was before. He loved to help the teacher and the other three children. It is also worth noting that playing with the interactive objects, such as the swing or seesaw, or to be allowed to explore the contexts which will be learned in later lessons, can be great rewards for these children. Once the children conducted learning by playing in the virtual environments, physical rewards such as cookies or stickers were no longer necessary. Learning by playing itself can be a good reward. Moreover, those children loved to play with the interactive objects with their peers. After comparing the oral output of the four children in the recorded learning process, it was also found that they produced more Mandarin output while playing with their peers than they did while playing alone because they loved to share the experience with others.

According to the findings regarding game functions described above, four guidelines are given below.

- Although the levels should be completed sequentially or in parallel depending on the learning contents and children's abilities, as the children's experience and abilities improve, the design can be flexible to increase the excitement and also to meet children's various abilities.
- The feedback given to children during the learning process should be simplified to ensure that it is correctly and promptly understood by children.
- The rewards can be offered in different ways. For example, allowing children to play some interactive toys or equipment in 3D virtual worlds and providing them with some 3D virtual objects, such as a lightsaber or a fancy sports car.
- The interactive objects that can be played by multiple users at the same time are more popular than those that can be used by one person at a time.

Although more and more researchers have proved the benefits of learning in 3D virtual worlds to disabled learners' learning needs, they also agree that those virtual environments should be appropriately adapted. The design proposed in the current study is based on the evidence-driven and individualized design approach, which not only echoes the design principles of 2D web-based learning for disabled learners (Debevc et al., 2007; Habib et al., 2012; Muzio & Serra, 2001; Sharma &Sharma, 2013) but also expands the general design principles of 3D virtual worlds for disabled users (Kruger, 2014). Kruger (2014) argued that Second Life, OpenSim, or any other 3D virtual worlds should be appropriately adapted to allow blind people to look for or classify the virtual objects as easily as sighted people do. The design principles proposed above are based on the semester-long observation of the four disabled children with 3 kinds of disabilities and delayed language development. Therefore, the guidelines based on the design principles of learning environments would be more user-specific for HCI designers when the target users are under the same conditions. However, as only four children with three different kinds of disabilities participated in this study, further investigation focusing on other kinds of disabilities and on a larger scale of participation is needed in the future for obtaining more detailed design principles for turning 3D virtual worlds into a more effective learning environment for disabled learners.

The children's perspectives and parents' comments

After finishing the two-cycle learning, all the children were individually interviewed by their special education teacher. They answered the questions as listed in Appendix A. Besides, considering their reading abilities, all the questions were orally asked by the same teacher and children's answers were recorded and transcribed later. Table 2 lists the summary of the children's answers. It can be found that all the four children agreed on the benefits of learning and playing in the 3D virtual contexts to their LCS and learning motivation. They all thought it was easy to use the system. And the authenticity of the 3D virtual contexts is quite high according to their perspectives.

Table 2. Children's answers to the interview questions

Dimensions	Children A (ASD)	Children B (ADHD)	Children C (ADHD)	Children D (mild MR)
Satisfaction	I like it VERY MUCH. All the units are very interesting, especially the fast food restaurant. The crabs in there are funny. I wish I can play with my sister after school.	I like it. It is interesting, especially when I was at the airport, in the zoo, and in the playground. I love the fast food restaurant, too.	I love it. It is lots of fun. I loved all the interesting places, like the zoo, and the airport and somewhere near the bus stop. I wish I can play it again. The more units, the better.	I like it. I do not fear learning in that. I loved the High-Speed Train station and the zoo and crossing the road.
Usefulness	I learned many vocabulary words. I can say many words, like cucumber, tomato, chees, … Learning in there helps me concentrate on learning because I love everything. I can say sentences better than before.	Playing in there helps me learn. I learned that I have to watch the cars when crossing the road, especially to watch the traffic lights. It helped me concentrate on learning. I now can say a lot more sentences and item names.	It helped me learn, especially memorize things. I did not forget what I learned in there. I can say a lot more words, but not many sentences.	I can concentrate more on learning. Playing in there helps me remember things, like those objects in the playground and at the airport. But I could not say more sentences yet.
Ease of use	It is very easy to use it. I become super soon after I started using it.	It is very easy to use since the first lesson. My PC only crashed once. After I re-logged in, there were no problems at all.	It is easy to use. I didn't need to wait and computers didn't crash.	My computer did not crash.
Authenticity	It is very authentic. I love my avatar very much. He is very obedient to me.	It is real, especially when I was in the playground.	Exploration in the worlds is like exploration in real world, especially in the playground. I learned I have to be careful when I cross the road.	The 3D virtual contexts are similar to real ones. It is like in a toy store. The airport is the most authentic one.

In addition to the children's perspectives and perceptions, their parents' comments on the benefits of the proposed learning approach to their children's oral expressing skills at home were also collected when they visited the school during Cycle 2. All except one parents (Child B's) provided the special education teacher with information on what and how their children talked at home. Child B's mother expressed that she did not know her boy's oral expressing skills after school because his child stayed with the babysitter during weekdays. In contrast, similar to their children, all the other three parents confirmed the effects of learning in the 3D worlds on their children's LCS development. Child A's (ASD) mother said her boy loved to share what he did and saw in the virtual worlds and even actively shared his learning experience in the virtual fast food restaurant with a waiter in a real fast food restaurant and asked him whether there were crabs in this restaurant. She said that he also asked her to buy him the same jeans his 3D avatar was wearing.

Similarly, Child C's (ADHD) mother also said that her boy could produce more words and sentences, especially those about night markets. Child D's (mild MR) mother was very surprised when she saw her girl smoothly used a computer to learn. She said that her girl expressed very high interest in the activities and even asked her to buy a computer at home. At the same time, all the three mothers also thanked the special education teacher for reminding their children about the differences between the virtual and the real world, especially safety issue, such as crossing roads.

Based on what is described above, it can be concluded that both children and their parents approved of learning by playing the proposed activities in a game-based virtual world in terms of its facilitating effects on the children's LCS development, and improvements in learning motivation and the children's concentration. The findings of the current study prove the benefits of the immersive, interactive, and authentic features of 3D virtual worlds to disabled children's LCS performances as well as echo the positive effects of game-based learning on children's learning (Wang, Chen, & Chan, 2016). They also show that although 3D virtual worlds possess inherent disadvantages which may challenge disabled children's use of this platform for pedagogical purposes, its potential as an educational application would be valuable if the HCI and learning activities are carefully designed. Therefore, the positive results obtained from this study are not only in line with the studies relating to 3D virtual worlds for special education students (e.g., Jeffs, 2010; Shih, 2014; Adamo-Villani et al., 2006), but also add to Lan's (2015) findings that the abovementioned specific features of 3D virtual worlds are able to enhance children's foreign language learning. Our results also echo the findings of the study by Huang and Liaw (2011), who stated that by immersing medical students into an authentic context benefits their learning motivation, attitudes, and performances. Briefly, according to the findings of this study, a carefully designed 3D virtual world is able to provide the learners, either ordinary or disabled, with a contextual learning environment in which learning becomes easier and more effective and thus learners' performances can be improved.

Conclusion

Disability comorbid delayed language development severely influences disabled children's school learning. They need special support, especially in their LCS development. The current study thus aimed at creating a friendly and engaging learning environment in 3D virtual worlds for catering the special needs of disabled children's LCS development. Because of the lack of literature relevant to HCI and learning environment design principles for achieving the abovementioned goal, a design-based qualitative approach was adopted in this study to identify the principles of designing a 3D virtual environment for disabled children's LCS learning. After the two-cycle design-based intervention, a list of design principles was identified. Furthermore, the effects of carefully designed 3D virtual environments on disabled children's LCS performances were also confirmed by the children and their parents. The results are positive and promising; nevertheless, only four children with three different kinds of disabilities participated in this study. In view of this limitation, the arguments made in this study should be further evaluated by investigating learning in similar contexts by children with other types of disabilities in the future. Furthermore, a larger scale of participants is also needed in future research to further corroborate the findings from this study.

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Appendix A

Interview questionnaire

Satisfaction:

1. During this semester, the teacher conducted teaching through a 3D virtual world. Do you like learning in this way? Why

□🏆Very interested □☺Somewhat interested □😐Not very interested

□☹Not at all interested

2. During this semester, the teacher conducted teaching through a 3D virtual world. Do you find it interesting? Why?

□🏆Very interested □☺Somewhat interested □😐Not very interested

□☹Not at all interested

8. Do you agree that your interest in learning is enhanced while learning in a 3D virtual world? Why?

□🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree

15. If time allows, would you agree learning in the 3D virtual contexts in the next semester? Why?

□🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree

Usefulness:

3. During this semester, the teacher conducted teaching through a 3D virtual world. Do you agree that it helps you learn? Why?

□🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree

4. During this semester, the teacher conducted teaching through a 3D virtual world. Do you agree that this way helps you concentrate more in classes? Why?

□🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree

5. During this semester, the teacher conducted teaching through 3D virtual contexts. Do you agree that your impression could be strengthened so you would not easily forget what you have learnt when learning in this way?

□🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree

6. During this semester, the teacher conducted teaching through a 3D virtual world. Do you think you have learnt many more names of objects and necessary vocabulary words? Why?

□🏆Much more □☺Slightly more □😐Slightly less □☹Much less

7. During this semester, the teacher conducted teaching through a 3D virtual world. Do you agree that you have learnt many more sentence structures? Why?

□🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree

12. Do you agree that the evaluation games in the 3D virtual contexts could help you clarify what you have learnt on that day? Why?

□🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree

Ease of use:

13. Do you agree that it is easy to operate the system? Why? If not, what are the problems?

    □🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree

14. Do you agree that the whole procedure of learning in the 3D virtual contexts was smooth without having to wait for long, without any screen freezes or any problems with the computers? If yes, what are they?

    □🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree

Authenticity:

9. Do you agree that you have more confidence in talking to others and chatting with others as an avatar in the 3D virtual contexts? Why?

    □🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree

10. Do you agree that your speaking skills have been improved while having conversations with other avatars in the 3D virtual contexts? Why?

    □🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree

11. Do you agree that when exploring the 3D virtual contexts as an avatar, you feel as if you were inside the game setting? Why?

    □🏆Strongly agree □☺Agree □😐Disagree □☹Strongly disagree