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Assistive Learning for Hearing Impaired College Students using Mixed Reality: a Pilot Study

Xun Luo
Qualcomm Research
5775 Morehouse Drive
San Diego, CA 92121
xun.luo@ieee.org

Mei Han
Technical College for the Deaf
Tianjin University of Technology
Tianjin, China 300191
meihan1201@tjut.edu.cn

Tao Liu, Weikang Chen, Fan Bai
School of Computer and
Communication Engineering
Tianjin University of Technology
Tianjin, China 300191
ltlmc@tjut.edu.cn

Abstract— **High quality college education for hearing impaired students is a challenging task. The most common practices nowadays intensively engage specially trained instructors, in-class and after-class tutors, as well as accessible infrastructure such as speech-to-text services. Such approaches require significant manpower investments of educators, staff and volunteers, yet are still highly susceptible to quality control and wide deployment issues. With proven records in education, mixed reality has the potential to serve as a useful assistive learning technology for hearing impaired college students. However, the fundamental technical and theoretical questions for this proposed endeavor remain largely unanswered, which motivated us to conduct this pilot study to explore the feasibilities. We designed and implemented a mixed reality system that simulated in-class assistive learning, and tested it at China's largest hearing impaired higher education institute. 15 hearing impaired college students took part in the experiments and studied a subject that is not part of their regular curriculum. Results showed that the mixed reality techniques were effective for in-class assisting, with moderate side effects. As the first step, this study validated the hypothesis that mixed reality can be used as an assistive learning technology for hearing impaired college students. It also opened the avenue to our planned next phases of mixed reality research for this purpose.**

Keywords- Mixed Reality; Assistive Learning; Hearing Impaired; Higher Education

I. INTRODUCTION

Hearing impairment is one of the most common disabilities. China, being the world's most populated country, also has the largest population of hearing impaired citizens. A national survey conducted in 2006 indicated that about 20.04 million people had different degrees of hearing impairment, among which 110 thousand were school-age children (between 6-14 years old). And every year 20 to 40 thousand newborns were clinically diagnosed to be deaf [1]. With China's economic growth and development in social welfare, college enrollment of hearing impaired students increased actively annually at over 10% rates during the past several years. High quality college education for hearing impaired students thus becomes an important matter for the society.

Successful college education can generate many positive effects to a hearing impaired student. It helps her to start a professional career smoothly and have better immersion into a hearing-dominant society. Not only can the hearing impaired person's life quality be largely improved, the independence she gained from this would also benefit the society in many indirect ways. Through many years' practice at successful deaf-educating institutions, like the National Technical Institute for the Deaf at Rochester Institute of Technology (NTID-RIT, http://www.ntid.rit.edu) in the United States, the following means of assistance has proven to be effective for the hearing impaired students:

- **Specially trained instructors**. Such instructors can teach with both verbal and sign languages in the class. The hearing impaired students can combine information received from limited hearing, lip reading and sign reading to maximize their understanding of class instruction.
- **In-class and after-class tutors**. These roles are served by paid staff members, or hearing student volunteers. In-class tutors assist their hearing impaired partners to focus on important class information, as well as aid the two-way communications between instructor and their partners. On the other hand, after-class tutors help on reviewing subjects that were taught during the class, work hand-in-hand with the hearing impaired students on homework assignments, and prepare together for quiz and exams.
- **Accessible infrastructure**. Among the multiple offering options, the most useful accessible infrastructure is the combination of speech-to-text devices and typists. Electrical devices capture the verbal communications in the class, and process them into rudimentary texts. Typists then refine the machine-processed results into error-free texts for displaying. Giving hearing impaired students the help needed in addition to their own lip- and sign-reading efforts.

However, these traditional means of assistance have their natural limitations. First of all, although it is possible to train a considerate number of instructors to use sign language, fully training coverage for all the faculty members in an inclusive university is far from feasible. This is not yet considering the proficiency level variations among sign language-trained instructors. Such factors more or less discount hearing impaired students' learning results in comparison to their hearing counterparts. Furthermore, the ideal team of tutors should be hearing students learning the same subject, doing relatively well in their studies, and offering the same useful help to as many hearing impaired partners as possible. This is not practical either given the limited energy and time of the volunteers. Last but not least, it is expensive to equip all learning environments with accessible infrastructures. Even if university budget allows a campus-wide deployment, maintenance of such infrastructure would be a daunting mission to accomplish. In summary, traditional approaches require significant manpower investments of educators, staff and volunteers, yet are still highly susceptible to quality control and wide deployment issues.

Mixed reality [2] is a promising candidate technology to address some of the limitations described above. In a mixed reality environment, presentations of both the virtual and real world co-exist and are associated with each other, but the two do not necessarily require highly accurate spatial registrations. These characteristics fit our assistive learning scenario well: we can define the actual classroom, include instructor and students, as the real world component in the mixed reality environment. In conjunction with the real world component, we can add virtual presentations that fulfill the functions of some or all of the three traditional assistive approaches. The advantages of mixed reality-based assistive learning are more controllable quality across multiple sessions, easier employment of new virtual world characters and other elements, as well as faster and lower-cost deployments in new instruction settings. On the other hand, the challenges of utilizing mixed reality include several fundamental technical and theoretical questions that haven't been answered yet: how to design a mixed reality system that relies primarily on non-verbal communications? Are there learning improvements using such a system, and to what extent? Which side effects could the mixed reality system produce, and how should we minimize them? To the best of our knowledge, there is no existing literature about using mixed reality about assistive learning for hearing impaired college student at the time this paper is written. The research work presented here was thus largely motivated by this fact.

We designed and implemented a mixed reality system which simulated in-class assistive learning, and tested it at the Technical College for the Deaf at Tianjin University of Technology -- China's largest hearing impaired higher education institute. 15 hearing impaired college students took part in the experiments and studied a subject that is not part of their regular colloquium. Results showed that the mixed reality techniques were effective for in-class assistive learning, with moderate side effects. The contributions of this work can be summarized into three aspects. Firstly, the construction of a mixed reality system which is suitable for use with minimal verbal communications, and targeting at the classroom setting of a higher education institute. Secondly, evaluation experiments with real – rather than simulated -- subject learning sessions and hearing impaired college students, as well as the collected data of the experiment series. Lastly, the proposal of a multi-phase roadmap to perfect the implemented mixed reality system, and the step-by-step plan to put it into practical use in the next few years.

The rest of this paper is organized as follows. Section II reviews works in the literature that are pertinent to this research. Details about the design and implementation of our mixed reality system are presented in Section III. We also describe in the same section setup of the evaluation experiments. Experiment results and analysis are provided in Section IV. In Section VI conclusions are drawn, and the roadmap of future work is laid out.

II. Related Work

Usage of virtual environments for assistive learning has found its way among a plethora of application areas, which can be categorized along the reality-virtuality continuum [3].

Examples of full- or semi-immersive virtual learning systems in the early days included flight/driving simulators, virtual assembly lines, simulated operation rooms, just to name a few. Research projects in the recent years that use virtual environments move further beyond. They pay attention to not only virtual objects, but also virtual humans and avatars that possess certain levels of intelligence. Some notable works are conducted at University of Southern California and University of Florida. Kenny et al at USC's Institute for Creative Technologies (ICT) constructed a virtual human called Sergeant Rockwell [4], and used the immersive environment which incorporated this virtual human for military scenarios trainings. By using their system, Soldiers can learn critical skills such as battlefield leadership, situation control, cross culture negotiation, and so on by interacting with the virtual environments and the virtual humans within. Another virtual human project at ICT built two virtual female characters, named Ada and Grace respectively, to serve as museum guides at the Museum of Science in Boston [5]. The two virtual characters used natural language interaction and had near photoreal appearance. Such utilization of virtual human technology greatly increased the interest and engagement of middle school students in science and technology. On the other hand, University of Florida researchers focused more on virtual learning environments for medical students. Lok in his 2006 article [10] gave an overview about the work of using virtual patients to train communication skills of medical school students. His results confirmed the feasibility of using virtual humans to simulate patient-doctor relationship. Another important finding was that domain-specific knowledge and virtual human fidelity were among the key factors to affect the effectiveness of such environments. In several follow-up projects, virtual patients and standardized actors were compared with regard to accuracy of describing abnormal physical findings [6] and effectiveness of general doctor diagnosing session interactions [7], the acceptance of medical students to such virtual patients were qualitatively and quantitatively was analyzed [8], and the potential of including virtual human in medical school curriculum was evaluated [9].

Computer and camera hardware improvements, as well as progresses in computer vision research during the past decade, fostered advances in augmented reality and its application in education [13]. Due to the large number of such applications, we just list two representative works in this section. Kaufmann and Schmalstieg used the mobile collaborative augmented reality system "Studierstube" to build a tool called Construct3D [11] and used it in class room instructions for mathematics and geometry. Their experimental results showed that Construct3D was easy to learn, encouraged experimentation with geometric constructions and improves spatial skills. Liarokapis et al presented an educational application that allows users to interact with 3D Web content (Web3D) using virtual and augmented reality [12] and illustrated four mechanical engineering themes (machines, vehicles, platonic solids and tools). They did not conduct quantitative user study but implied that the system was useful and accepted by instructors as well as students.

More directly related to our research are the works using virtual reality for hearing impaired children learning and training. One of the first literatures that discussed the feasibility of VR-assisted learning for hearing impaired children was the article by Alonso et al in 1995 [14]. It discussed several multimedia technologies and frameworks that could improve the communication skills of hearing impaired children. VR was one of those technologies. Due to the limitations of VR system performance and fidelity at that time, feasibility of VR utilization was discussed but not evaluated in the article. Later Passig et al carried out multiple virtual reality research projects for hearing impaired children, covering a wide range of learning and training topics. Their representative works include [15] which used VR for early intervention of cognitive skills, [16], [18], [19] which focused on abilities of flexible thinking, spatial understanding and induction respectively, and [17] which described improvement of understanding in time concepts. The common evaluation methods among these works consist of using VR to replicate one or multiple tasks in the real world, and undertaking two group comparisons (hearing impaired children vs. hearing children using virtual environment; hearing impaired children using virtual environment vs. real environment). Results and statistical analysis showed that VR was helpful in these studies. Adamo-Villani et al at Indiana University also used VR to investigate assistive learning, on the subjects of mathematics and sign language learning for deaf children. Unlike the approaches adopted by Passig et al, their means were using virtual animal characters ("Bunny" and "Lizard") who were capable of storytelling and language signing to help deaf children throughout the learning process [20], [21]. The evaluation results were qualitatively positive.

Differentiations of our research from existing literatures can be viewed from two angles. Along the reality-virtuality continuum, our work falls into mixed reality rather than virtual reality or augmented reality categories. In-class assistance, through the presentation of virtual contents, is regulated by the dynamics of real world events and conditions, but without the constraints for tight spatial registration. For the application area, our investigation focuses on college education which is post-secondary. The classroom settings, learning style and student bodies are drastically different from K-12. Good understanding of human instructors and smooth colocation with hearing students are key benchmarks for success in this pilot study.

III. THE MIXED REALITY SYSTEM

We designed the mixed reality system composed of two main components. One component is the assisting console controlled by a hearing student. The other component is the virtual character displaying viewport which fulfills assistance to hearing impaired student. The two components are interconnected through network. In a real-world classroom, live lecture is observed by both the hearing student and the hearing impaired student. In our system without losing generality, we used recorded videos to substitute live lectures. It is trivial to replace recorded video with streamed video of a live session.

Both components use a dual-screen setup. Within each component, one of the screens displays lecture video, and the other screen displays mixed reality user interaction or rendering content. Videos on the screens of both components are synchronized in time. The hearing impaired student side of the system has a virtual character shown on the user content screen which can take predefined actions, while the hearing student side of the system has a control UI shown on the user content screen to manipulate virtual character at the other end to perform such actions, in the "Wizard of Oz" fashion.

A. System Configuration

Figure 1 illustrates the hardware configuration of the mixed reality system. At the hearing student side, Screen 4 displays the lecture video, and Screen 3 displays the assisting console UI. A dual display output computer PC 3 drives both screens. PC 3 is connected through network to the hearing impaired student side.

At the hearing impaired student side, Screen 2 displays the lecture video, computer PC 2 drives Screen2. Screen 1 displays the virtual character, the Tablet drives Screen 1. PC 1 is connected through network to the hearing student side, and interconnects with Tablet through USB. PC 1 serves as the network proxy as well as UI proxy for Tablet due to the reason that Tablet itself does not have an Ethernet connection.

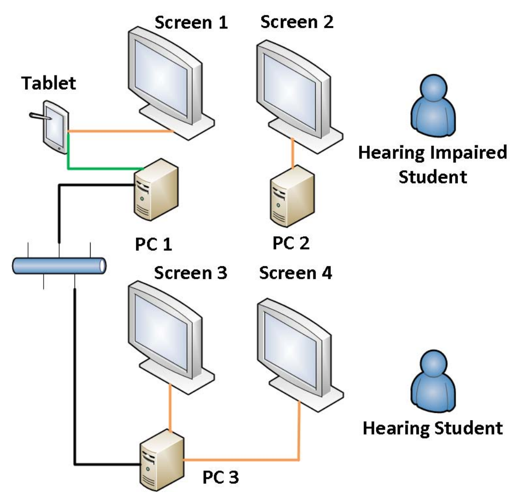

Figure 1 System configuration, different types of connections are color-coded: black – network connection, orange – display connection, green – USB connection.

B. Software Components

Architecture of the software components is sketched in Figure 2. On the assisting console side, the hearing student interacts with the UI to issue commands and monitor response indications. The commands, which are outgoing from this side's point of view, are encoded from their visual representations in the UI into textual forms and sent over the network. Likewise, the responses, which are regarded as incoming, are generated in textual forms on the virtual character side and decoded to be presented as graphical indications. Command Encoder and Response Decoder undertake these two functionalities respectively. The Network Transceiver component handles network I/O.

On the virtual character side, a Port Mapper forwards packets both ways between the local loopback and the external network interfaces. This is due to that the USB interconnection between Tablet and PC 1 only binds to the local loopback network interface, but network egress and ingress traffic on PC 1 both take place on the external network interface. Forwarded packets are subsequently handed to the virtual character side Network Transceiver whose functionality is similar to its counterpart on the assisting console side. The UI Proxy on PC 1 collaborates with a corresponding UI Stub on Tablet to deliver the control commands to Virtual Character, as well as relaying the responses from Tablet about the execution results of those commands.

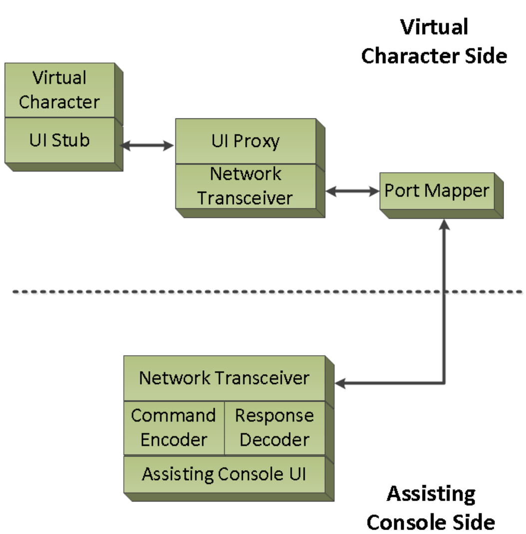

Figure 2 Software Components of the mixed reality system

We give greater details about the virtual character viewport and assisting console UI below, because they are the immediate interfaces of our mixed reality system to its users, hearing impaired student and hearing student alike. There are two state-of-art ways to construct virtual characters. The first one is to use a commercial character database with graphical models and control APIs. By incorporating the control APIs into custom-designed application, the virtual characters can be manipulated as desired. The other way is to build the virtual characters from scratch, which gives more flexibility in character action and appearance control, at the trade-off of significantly more work. The approach we used is different from both of them based on an interesting observation of contemporary mobile device applications.

A group of virtual petting applications, called "talking friends" are available on most major mobile platforms. In each of these applications a distinct virtual character acts in the role of a stage performer, capable of showing a number of eye-catching actions. In Figure 3 are the screenshots of two such virtual characters. The cat on the left is called Tom and the dog on the right is called Ben. The "talking friends" applications share common characteristics: they all offer interfaces for the mobile device user to play with through touch screen tapping or soft keyboard stokes. In Figure 3 for example, user can tap the four round shape buttons on the left and right sides of the Tom character to make it drink milk, click a drum, make a face, etc. While for the Ben character, user can tap the five round shape buttons in the bottom of the screen to make it operate different test tubes, and play tricks according to the fictional chemical reaction results. Graphical designs of the virtual character actions are funny and have been tested with the acceptance of a massive number of application users.

In the mixed reality system we enable the UI Stub on mobile device, and send textual commands to the UI Proxy to mimic direct user interactions. By doing this, the virtual characters can be operated from the computer interconnected with the mobile device. Thanks to the forwarding functionalities provided by Port Mapper, it is further feasible for the textual commands to come from a remote source on the network. For example, let us assume the Tablet screen resolution is 800 by 1280, then textual command "tap 700, 1000" will trigger exact the same action as the one when user tapped coordinate (700, 1000) on the screen with his fingers, which makes Tom to click the drum. As shown in Figure 4, the assisting console UI provides options to the user to choose different virtual characters: Tom the Cat, Ben the Dog or Gina the Giraffe. After a virtual character is chosen, the available actions are loaded into the right side panel of the UI, with user-understandable short descriptions. Once a button is clicked, the command is encoded into textual forms by the Command Encoder and sent to the other side through network connection.

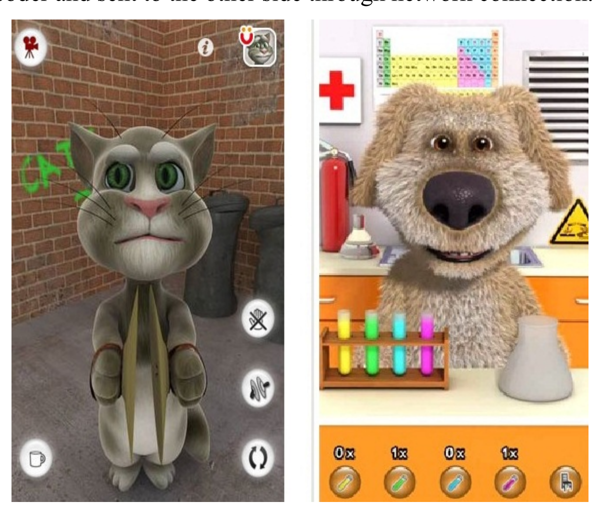

Figure 3 Off-the-shelf virtual characters

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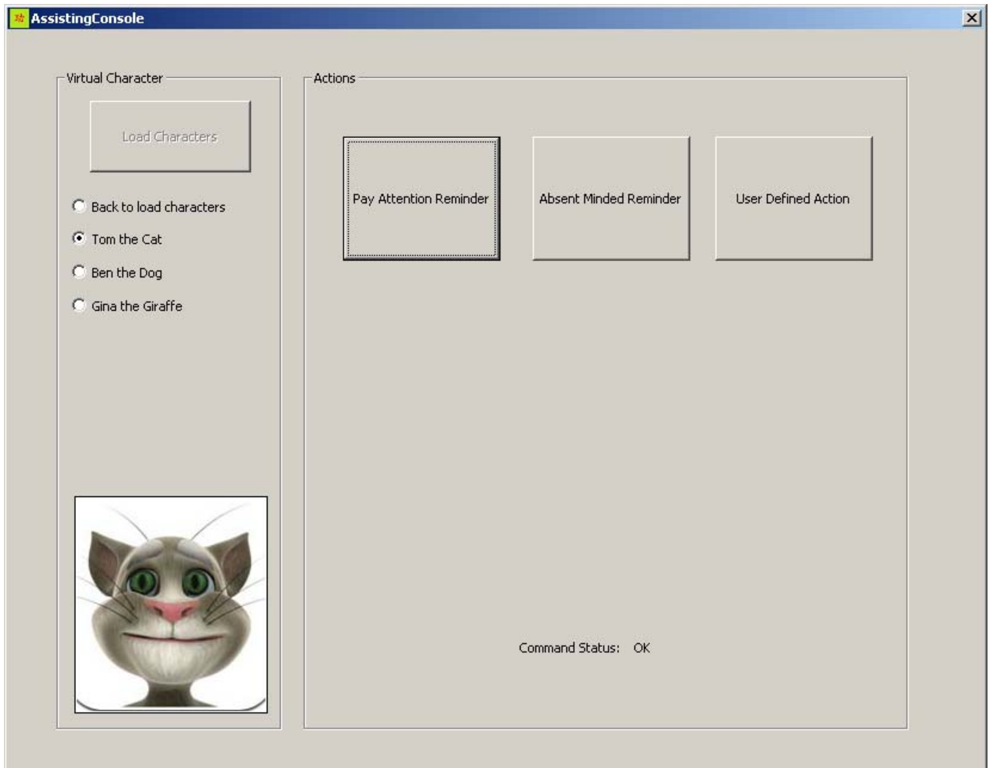

Figure 4 User Interface of the Assisting Console.

IV. EVALUATION EXPERIMENT

We evaluated the implemented mixed reality system at the Technical College for the Deaf at Tianjin University of Technology, China's largest hearing impaired higher education institute. The Technical College for the Deaf has an enrollment of over 400 undergraduate students with different degrees of hearing impairments. Programs offered at the College include Computer Engineering and Art Design. Tianjin University of Technology provides a partially inclusive learning environment for hearing impaired students: they share all common infrastructures with hearing students, but different class instructions. According to a survey conducted by the College several years ago, most hearing impaired students would welcome all-inclusive education under which they are able to study together with hearing students and access all course offerings at the University. The College is also planning all-inclusive education on its roadmap, but yet has to overcome the road blocks of lacking of specially trained instructors as well as hearing students to serve as in-class and after-class tutors. Faculties and students showed strong interests in exploring the possibilities of using mixed reality for assistive learning.

The evaluation was thus conducted in the form of an experiment which simulates in-class assistance offered by a hearing student to his/her hearing impaired classmate.

A. Experiment Setup

A spacious computer laboratory with over 80 dual-screen PC units at the College was identified to be an ideal experiment venue. The laboratory features a multi-row layout of units, along each row the units are kept apart from each other, creating a comfortable personal space for every user. Each unit consists of a dual display output Windows PC and two 19 inch LCD monitors placed side-by-side. All units are connected through 100 Mbps Ethernet adapters to a local area network in the laboratory. The hearing student unit and the hearing impaired student unit were chosen to be five rows apart from each other, with audio output routed to headset on the former and muted on the latter. By using this setup both students had no other means of communication except for the one through the assisting console and virtual character. At the hearing impaired student side we also made a small modification to the original unit setup. One of the two LCD monitors was detached from the Windows PC and connected to a Samsung Galaxy 10.1 tablet through HDMI-DVI signal conversion (HDMI output from the tablet and DVI input to the LCD monitor). A separate Windows laptop acted as the network and UI proxy for the Galaxy tablet, with its own Ethernet connection to the laboratory network. Three "talking friends" applications were installed on the Galaxy tablet, including "Talking Tom" (cat), "Talking Ben" (dog) and "Talking Gina" (giraffe).

B. Video Lectures

There were several criteria that we set for a good video lecture before selection. First and foremost, it should be a subject new to both the hearing impaired and hearing students. Second of all, visual contents alone of the video lecture should be sufficient to convey the knowledge points, but not at a level that solely by watching the silent video will ensure good understanding of the lecture. In another word, we would like audio to be an important assisting cue in the video lecture, thus the effect of substitution of audio cue with mixed reality assistance can be best evaluated. Lastly, knowledge points of the lecture would be preferably evenly distributed across its duration, so expectations of assistance given last throughout the learning session.

Our source for video lectures selection is the Chinese video website iCourses operated by the Higher Education Press (http://www.icourses.edu.cn). As of year 2012, iCourses has a collection of hundreds of video lectures recorded at the classrooms of over a dozen prestigious Chinese universities. Backed up by the Ministry of Education, this archive is expected to grow into a 5000-video collection by year 2015.

Based on the criteria set above, we selected the course "Human Anatomy" offered by Central South University. The course contains six episodes, and we specifically chose episode one of the series "Introduction to Human Anatomy: Bone Structures". As a medical school course, this lecture is not related to any regular colloquium at Tianjin University of Technology. So it is a new knowledge area for both the hearing impaired and hearing students. As the introductory episode for first-year medical students, the course is of reasonable difficulty level for people with no medical background. Episode 1 has rich slide presentation scenes across its duration, sufficient enough to convey all the knowledge points. However, without hearing the instructor, it is hard to tell what the knowledge points within the video are. The video has closed captions at the bottom, so we taped a paper strip at the bottom of the LCD monitor when playing it in full screen mode, to block out these captions. Length of the video is 26 minutes with no breaks, which is the common class duration in Chinese universities.

Three hearing students were asked to watch the episode with audio on, and record the important knowledge points they believed to be important. They performed this task individually without communicating with each other. The final knowledge points were selected based on the common part of their markings. The three students were then assigned to jointly make a quiz which contained three multiple-choice questions for each knowledge point. Using this process, ten knowledge points were identified from the episode as listed in Table 1, and a thirty-question quiz was prepared.

TABLE 1 KNOWLEDGE POINTS IN THE EXPERIMENT LECTURE VIDEO

ID	*Description of the Knowledge Point*
1	What is human anatomy
2	Basic formation of human body
3	Nine systems of the human body
4	The movement system
5	Basic structure of bones
6	Sclerotin and periosteum
7	Marrow
8	Chemical and physical characteristics of bones
9	Growth and development of bones
10	Membrane bone and enchondral ossification

C. *Testing Subjects*

Fifteen hearing impaired students were recruited from the College to participate in the experiment, spanning across sophomore to junior grades. Among them twelve are male and three are female. The age average is 21.4 and standard deviation is 0.63. The students had no other disabilities besides hearing impairment.

Three hearing students from the School of Computer and Communications Engineering volunteered as assisting tutors. All tutors are male. Two were at sophomore grade and one was at junior grade.

None of the hearing impaired and hearing students were experienced with virtual environments before the experiment.

D. *Assisting Protocol*

The hearing impaired and hearing students were seated as described in Section IV.A. The hearing student could listen to the accompanying audio of the video lecture through headset. Also the hearing student always sat in the back row so he can observe the behaviors of the hearing impaired classmate, but not vice versa. Each experiment session included one hearing impaired student (out of the fifteen) and one hearing student (out of the three) in a pair. The playing back to video lectures on both ends were timed to start simultaneously, so that what both students watched were in synchronization.

The hearing impaired student was instructed to feel free to take notes of any knowledge points he/she believed to be important. It was also told that there would be a quiz after the learning session. Possible virtual character actions and their meaning were explained in detail. Once the learning session started, whenever the video lecture was at a knowledge point, the hearing student manipulated the virtual character to perform an action (in the experiment sessions, it was the "pouring milk" action by Tom the cat). Whenever the hearing student found his classmate might be absent minded to the lecture because of not following or other reasons, he also sent a command to make the virtual character to perform another action (in the experiment sessions, it was the "clicking drum" action by Tom the cat).

E. *Data Collection*

We collected both subjective and objective data of the evaluation experiment.

Each hearing impaired student was interviewed after the experiment and asked about his/her general opinions of the mixed reality system. Such comments were recorded as subjective data.

For the objective data, two types of records were logged. The first type is the hearing impaired student's score performance on each knowledge point in the after-class quiz, as well as his/her rating about whether or not the assistance received during learning was helpful for that specific knowledge point. The scores were marked in point scales -- one point for each multiple choice question correctly answered, and zero point for the ones incorrectly answered. The second type is the hearing impaired student's rating during the learning session about the accuracy of received absent-minded reminders. If it was believed that the reminder was received while he/she was indeed absent-minded, the reminder was rated as accurate, and otherwise it was rated as a false alarm.

V. RESULTS AND DISCUSSIONS

All fifteen hearing impaired students completed evaluation sessions without dropping out or recording invalid data. Completion of the fifteen sessions took four days during the computer laboratory's non-peak hours.

Subjective comments about the experience of being assisted by a virtual character were mostly very positive. Students rated this approach as novel, interesting and fun. Thirteen of them felt that with such help, it was easier to catch the pace of the lecture, understand the importance of knowledge points, and keep focused across the entire learning session. Two students (subject #10 and #11) expressed different opinions from the majority. Subject #10 said that although the system was interesting, reminders from the virtual character were a little bit too much and bothered his normal way of study. Subject #11 mentioned that he was in general not accustomed to being assisted by a tutor in class. Due to the common ownership of mobile devices and popularity of "talking friends" applications, all students were familiar with Tom the cat character and showed good acceptance, treating the virtual character as the same as a real human classmate. This was also attested by the fact that although every student knew that the virtual character was operated by a hearing student out of his/her sight, none of them in the comments referred to the hearing student as the in-class tutor but just Tom the cat.

Objective data also supported the effectiveness of the mixed reality system. Figure 5 showed the results of quiz answering and association of scores to received assistance, which was answered by the hearing impaired students in conjunction with each quiz item, in the form of percentage ratio. Average ratio across the subjects was 85%. If we set 80% as the cut off line for effective assistance in knowledge points, then twelve out of the fifteen students had found mixed reality system to be effective.

Figure 6 shows the number of observed absent-mindedness for each hearing impaired student by the hearing student, as well as number of effective reminders claimed by the hearing impaired students. It can be observed that absent-mindedness was very common when learning without audio cue – on average each subject had 4.5 such occasions observed during the 26-minute video lecture. In the meantime, 90% of such reminders were deemed as accurate. This shows that absent-mindedness reminder of the mixed reality system is also effective.

It is worth noting that subject #10 and #11's knowledge point capturing scores and absent-mindedness reminder evaluations are in line with their general acceptance of the mixed reality system. This establishes the link between acceptance and effectiveness, which is similar to the situation when assistance is offered by in-class tutors in the traditional approaches.

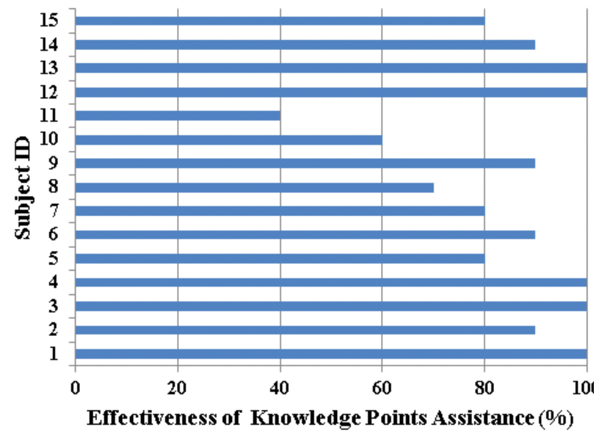

Figure 5 Results of knowledge points assistance

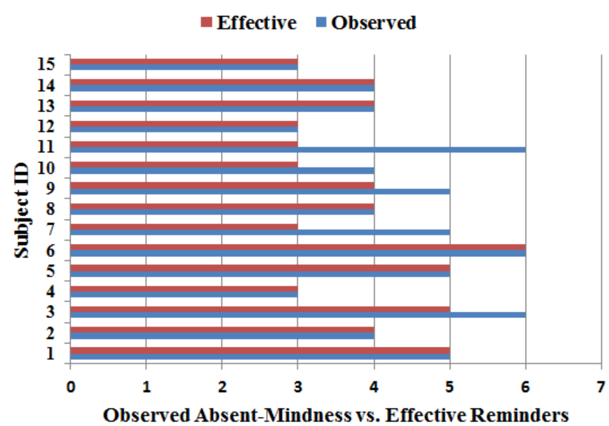

Figure 6 Results of absent-mindness assistance

VI. CONCLUSIONS AND FUTURE PLANS

In this pilot study we designed and implemented a mixed reality system to explore assistive learning for hearing impaired college students. Preliminary results were promising and verified the feasibility of such approaches.

Table 2 describes a research roadmap with three phases for the current and ongoing work. It can be seen that the pilot study completed phase I, setting up the foundation for future developments. In the proposed phase II of research, we plan to use directed lecture videos at TJUT in addition to iCourse videos, substitute virtual animal characters with virtual humans, and utilize 3D partially immersive displays for side-by-side presentation of lecture video and virtual characters. Focuses of phase II of the research include fidelity of virtual human and improved triggering events and means of assistance. In the further planned phase III of the research, we expect to use 3D fully immersive displays, and create more intelligence for the virtual characters so that they can accomplish self-control. The ultimate goal is a practical system to be used in real classrooms.

TABLE 2 RESEARCH ROADMAP AND PHASES

Phase (Duration)	**Agenda**		
	Lecture Content	***Mixed Reality Environment***	***Focus of Research***
I (six months)	iCourse videos	- 2D side-by-side: lecture video and virtual character - virtual animal characters - wizard of Oz control of virtual characters	- feasibility validation of mixed reality for assistive learning - evaluation of student acceptance - exploration of triggering events and means of assistance
II (six months)	iCourse videos and directed TJUT videos	- 3D partially immersive side-by-side: lecture video and virtual character - virtual human characters - wizard of Oz control of virtual characters	- fidelity of virtual human - improved triggering events and means of assistance
III (one year)	Directed TJUT videos	- 3D fully immersive blended: lecture video and virtual character - virtual human characters - self-control of virtual characters	- intelligent cognition and behavior of virtual human

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