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Improving the authentic learning experience by integrating robots into the mixed-reality environment

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ABSTRACT

The main aim of the modern popular teaching method of authentic learning has been to provide students with everyday-life challenges that develop knowledge and skills through problem solving in different situations. Many emerging information technologies have been used to present authentic environment in pedagogical purpose. However, there are few studies that have been discussed the sense of authenticity and characters in scene and how students interact with the characters involved in the task. We designed a system, RoboStage, with authentic scenes by using mixed-reality technology and robot to investigate the difference in learning with either physical or virtual characters and learning behaviors and performance through the system. Robots were designed to play real interactive characters in the task. The experiment of the study conducted with 36 junior high students. The results indicated that RoboStage significantly improved the sense of authenticity of the task and also positively affected learning motivation. Learning performance was conditionally affected by RoboStage.

1. Introduction

Inspired by situated learning theory, Herrington and Oliver, (2000) proposed a modern pedagogical concept named “authentic learning”. Authentic learning typically relates to real world, complex problems and their solutions, using role-playing exercises, problem-based activities, case studies, and participation in virtual communities of practice. Going beyond content, authentic learning intentionally brings into play multiple disciplines, perspectives, ways of working, habits of mind, and communities (Lombardi, 2007).

Herod (2002) presents a clear description of authentic learning as follows: “*In this type of learning, materials and activities are framed around “real life” contexts in which they would be used. The underlying assumption of this approach is that material is meaningful to students and therefore, more motivating and deeply processed*.” Students immersed in authentic learning activities cultivate the kinds of “portable skills” that newcomers to any discipline have the most difficulty acquiring on their own (Jenkins, Clinton, Purushotma, Robinson, & Weigel, 2006), including the judgment needed to distinguish reliable from unreliable information, the patience to follow longer arguments, the synthetic ability to recognize relevant patterns in unfamiliar contexts, and the flexibility to work across disciplinary and cultural boundaries to generate innovative solutions. Cognitive scientists are developing a comprehensive portrait of the learner. Three principles (Lombardi, 2007) illustrate the alignment between learning research and authentic learning: learners look for connections, long-lived attachments come with practice (Bahr & Rohner, 2004), and new contexts need to be explored (Bereiter & Scardamalia, 1985).

1.1. Mixed-reality learning environment

It is difficult to implement authentic learning activities. Certain experiments are too dangerous, difficult, or expensive to conduct in a classroom. However, the emergence of innovative technological tools yields some possibilities. Jonassen, Peck, and Wilson (1999) addressed that technologies can be used as tools for exploring knowledge and solving real world problems and mediating collaboration and communication. With the help of the Internet and technologies for communication, visualization, and simulation, we can offer students

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a more authentic learning experience. Learners are able to gain a deeper sense of a discipline as a special "culture" shaped by specific ways of seeing and interpreting the world. The mixed reality (MR) is one important technological support for today's authentic learning environments (Lombardi, 2007).

MR has been used as an educational tool in recent years in applied fields such as earth science, mechanical engineering, and medical imaging (Pan, Cheok, Yang, Zhu, & Shi, 2006; Strangman & Hall, 2003). One of the main reasons using MR in educational and training purposes is that it supports high interaction and can present a virtual environment that resembles the real world. Students are able to involve in abstract spaces, a computer-generated version of real world objects or processes. These simulations can take many forms, ranging from computer renderings of 3-D geometric shapes to highly interactive, computerized laboratory experiments.

1.2. Characters in the learning activities

Besides the appearance of the interactive authentic environment, interactive characters are also an essential element of authentic learning activities. For example, when students learn about China's three-kingdom period in a history class, the scenario requires not only palaces and battlefields but also heroes, soldiers, and folks from that age. Van Vugt, Konijn, Hoorn, Keur, and Eliëns (2007) summarized three reasons for the efficacy of character use in learning activities. First, characters may properly attract the learner's attention, especially when they have an eye-catching appearance. Second, virtual characters may evoke feelings of the presence of 'another person', which might consequently affect task performance. Third, realistic characters may make people feel comfortable and may be likeable.

Most of the characters in a mixed-reality environment are virtual characters. However, recently, many studies have shown that a tangible user interface and physical characters are more enjoyable and engaging for users than a graphical user interface with virtual characters. Xie, Antle, and Motamedi (2008) investigated the relationship between interface style and school-aged children's enjoyment and engagement while doing puzzles. Pairs of participants play with a jigsaw puzzle that is created using three different interface styles: physical (traditional), graphical and tangible. Repeating play is used as an alternative indication of engagement. The result shows significantly more pairs present in the physical user interface and tangible user interface conditions engaged in repeat play—that is, starting the puzzle a second time. Andrew et al. (2007) provided key insight into the construction and evaluation of interpersonal simulators—systems that enable interpersonal interaction with virtual humans. They used an interpersonal simulator and designed two studies to compare interactions with a virtual human to interactions with a similar real human. In their experiment, 24 medical students elicited the same information from the virtual and real human, indicating that the content of the virtual and real interactions was similar. However, participants appeared less engaged and sincere with the virtual human. These behavioral differences likely stemmed from the virtual human's limited span of expressive behavior. Wainer, Feil-Seifer, Shell, and Mataríc (2007) attempted to test the hypothesis that physical embodiment has a measurable effect on performance and the impression of social interactions. Supporting this hypothesis would suggest fundamental differences between virtual agents and robots from a social standpoint and would have significant implications for human–robot interaction. They suggested that participants felt that an embodied robot was more appealing and perceptive of the world around it than were non-embodied robots, and they also demonstrated that the embodied robot was seen as the most helpful, watchful, and enjoyable character comparing to a remote tele-present robot and a simulated robot. Comparing a robot companion and a virtual companion in a mathematic game, Hsu (2007) concluded that children learning with robot animal learning companions display better concentration than those learning with a virtual one. Two reasons of this study were generalized based on these researches. First, characters are an essential element of authentic learning activities. Second, users engage deeply and feel more enjoyment with a physical character than with a virtual character.

These studies inspired us to explore the effectiveness of mixed-reality environments containing physical characters on authentic learning activities. Nowadays, however, few empirical studies have integrated tangible characters into an augmented reality environment to support learning. By designing robots aiming to interacting with students in a reality technology-supported learning environment, this study aims to examine the sense of authenticity and engagement in the integrated learning environment to better determine the effect on learning performance when students acquire and use knowledge in an authentic learning environment. Given this perspective, our research focuses on investigating:

- The difference in the subjective experience for students when a robot and a virtual character are used in the authentic learning activity.
- The influence of learning performance in the authentic learning environment with a robot.

2. Methods

2.1. Participants

The participants of the experiment are a class of 36 eight-grade students in a rural public junior high school in Taiwan. The male–female ratio is 1:1. All of them are Chinese speakers who had learned English as foreign language. They have five-hour English course each week. The teacher usually spends 7 h for a course unit. The teacher and the student didn't use the learning device before. The 36 students are divided into 4 groups by random. Each group has three subgroups: 3 students in charge of commanding the robot among them and one is the leader of the group, 3 students are responsible for answering the questions from the system, and 3 students read and look up answers in the lecturing notes. The content of our experiment is designed according to a course unit from their English textbook. The experiment was held as a regular course with their original English teacher.

2.2. Materials

In the experiment, we constructed a Learning platform, named RoboStage. RoboStage is a mixed-reality learning environment with robots designed at the National Central University in Taiwan (Chang et al., 2009). It is an authentic learning environment that extends a vertical screen with a platform and uses many multimedia features to improve the realistic nature of the simulation. The virtual scene was presented on the two perpendicular screens (the diagonal of each measured 80 inches). The operation of the learning system was changed

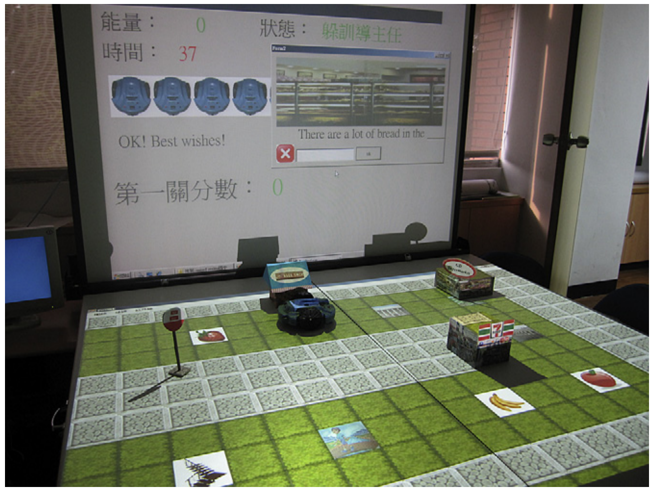

Fig. 1. The RoboStage.

from keyboard and mouse on the flat screen to voice and physical objects in the virtual world (as in Fig. 1). The robot, which could be remote-controlled to move and to make sounds, was placed on the stage to be the Task agent in the learning environment. It could autonomously act based on students' commands. Students could command the robot to move on the stage. If the robot approaches to the characters designed in the scene, a dialogue, an event, or a learning task would be triggered.

Considered to the completeness of functions and the potential popularization of this design in the future; the robot that we chose was the commercial educational robot Scribbler, with the IPRE Robot Kit manufactured by Georgia Robotics Inc. We made the robot move and speak by using a Bluetooth wireless connection and the sense inputs of robot through the built-in sensors. In this system, therefore, the students could talk to the robot based on the sentences in their textbook. They also could use some task-related objects that were stuck to a 2D barcode beforehand to fulfill the task. This design made students proceed with the task spontaneously in the authentic environment.

The RoboStage and events are designed according to the guidelines for authentic environments formulated by Herrington and Oliver (2000). It consisted of scenes, characters, and events (as in Fig. 2). The virtual streetscape was shown on the stage, including buildings, streets, and traffic signs. There are two kinds of characters in the scene: facilitators and local people. Facilitators would assist students in finishing the learning activity. For example, traffic police would answer questions and give directions. The local people were designed to simulate the real world. For example, there is a hot dog vendor who would gossip and a child playing with a ball. Students could talk to these characters and thus would trigger some events.

There are three kinds of events in the RoboStage: learning event, situated event, and blended event. The learning events played the main role in student learning and practicing in the activities. However, the authentic context contains relevant and irrelevant information in terms of simulating real-world situations (Herrington & Oliver, 2000). The event design on the authentic context includes pushing the learners move toward the goal, describing the context situation, and interacting with objects in the context for engaging learners. Situated events provide informative knowledge in accordance with the context. For example, a city local resident describes the environment of the city so that the learners can understand the information of the city. For those situated events that are related to the learning of the content in the textbook are called blended event. A blend event is an integration of learning and situated event. For example, the course unit is about introducing how to order food in a restaurant. One of the blend events is a task for the robot to order something from a restaurant on the RoboStage. Because of the relevant and irrelevant information, the authentic context became relatively complex. The complexity of the context is also essential to a realistic simulation of the real world (Uhlenbeck, 2002).

The experiment in this study was designed for a foreign language class in a junior high school. The learning materials were the sets of vocabularies, phrases, and sentences in the students' English textbook. The learning content in this experiment includes half of the vocabulary of the course unit. There were 25 unlearned words in the course unit. Ten words were randomly assigned to the RoboStage with

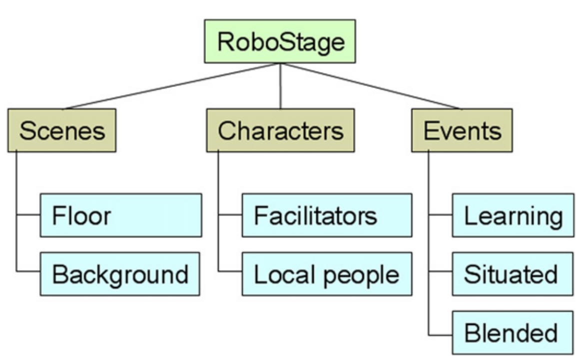

Fig. 2. The component diagram for RoboStage.

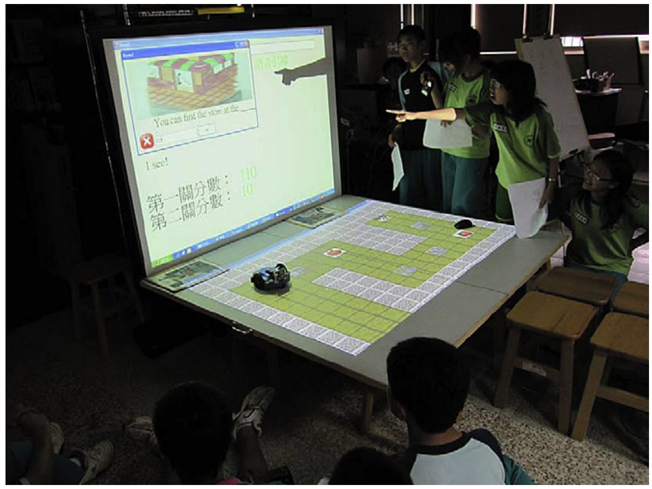

Fig. 3. Students learning using the RoboStage.

a robot, and another ten were assigned to the non-robot RoboStage as the control group. Another five words were the function words for commanding the robot. There were two questionnaires that were used to investigate the learning experience and learning performance. The learning experience included the sense of authenticity, engagement, and learning motivation. The evaluation of learning performance was focused on the degree of familiarity of the new words.

2.3. Procedures

We prepared a lecture note that contains the vocabulary and sentences which were used in the experiment. At the beginning of the experiment, the notes were delivered to all students. After that, the teacher gave a short lecture on the content in the notes. RoboStage took the original place of the whiteboard and teacher stage in the classroom. The students sit on their seats and were able to see the information shown on the RoboStage.

There were two phases of experiment that use different learning tools. In the first phase, groups A and B completed the learning activities without a robot in turn, while groups C and D used the RoboStage with a robot in turn. In the second phase, we swapped the robot and the non-robot environments. All students involved in the same authentic learning environments. The goal in the learning activities was the same for both the phases. In the non-robot mode, student controlled the virtual robot image and answered questions by a keyboard. On the other side, in the experimental group, students commanded the robot to complete tasks (as in Fig. 3).

Each group comes to the RoboStage to play for around 10 min. A task mission (get to a place on stage) was assigned for the group to complete in the context designed on RoboStage. There is a score for the group that depends on how good the robot achieves the goal. Most of the events and interactions related to learning units are shown on the vertical screen so that all students can see them clearly. For example, students were advised that they would like to go to a Michael Jackson concert with their robot friends. The students needed to find the address of the concert in the foreign city and made enough money to buy the tickets. The students needed not only to assist the robot in moving to the destination but also to obtain information and resources by finishing the job or providing the answer required by the characters in the virtual city. Moreover, the robot is autonomous and does not move precisely. Thus, the result is not predictable even when all the commands are correct. In the whole class period, all the students were engaging, watching, echoing what happen on stage, and looking for answers all the time even though there were no game-play group.

At the end of each phase, students were asked to complete a questionnaire according to their user experience. Referring to the authentic assessment factors proposed by Gulikers, Bastiaens, and Kirschner (2006), the experience questionnaire was originally developed to examine the experience of students who were working in an authentic electronic learning environment. We adapted this experience questionnaire for our learning system. The two questionnaires each consisted of 9 Likert-type items created around five scales that examined three aspects of the authentic learning experience: authenticity, engagement, and learning motivation. The exact list of items and results is listed in Tables 2 and 3.

Two weeks after the experiment, for assessing the degree of familiarity of the 25 new words (10 using the robot, 10 using the non-robot, and 5 for robot commands), another questionnaire was administrated by a self-evaluation form. The purpose of the questionnaire is to evaluate each student's ability to identify the meaning of the words, recall them, spell them, and comprehends them when they were spoken, as well as inquiring about the student's level of experience with each word. The items are listed here in Table 1.

Table 1
Vocabulary familiarity evaluation.

For example: bakery	SD	*D*	*N*	*A*	SA
I know the meaning of this word					
I remembered this word one week later					
I have experience in really using this word					
I can spell this word immediately					
I would know the meaning when others say this word					

Table 2
Learning experience with virtual characters.

Item	SD(1)	*D*(2)	*N*(3)	*A*(4)	SA(5)
Authenticity					
I feel what I am seeing is real when I use the keyboard and mouse to control the virtual robot on the screen		1	17	11	7
I feel like the virtual robot really moves in the scene		4	11	12	9
The virtual robot makes me feel that the learning activity is real	2	15	14	5	
Engagement					
I would concentrate on controlling the virtual robot to proceed with learning activities	1	1	14	10	10
I was involved in the learning activity because of the virtual character and the virtual scene	2	8	21	4	
I enjoyed the virtual character and the scene	2	8	18	8	
Learning motivation					
I like to learn English with the virtual character	1	5	10	12	8
I would use the virtual robot to learn English for a long time		4	13	8	11
I want to use the virtual character to learn English again		6	23	5	2

3. Results and discussions

Tables 2 and 3 show the results with relation to the students' learning experiences in the mixed-reality learning environments with virtual characters and with robots respectively. These tables present some interesting findings. At first, comparing to the students' experience with robot and non-robot modes, the participants expressed their preference learning with physical robots than virtual robots. By performing a paired *t*-test, we identified a significant difference in students' sense of authenticity ($t = 4.005$, $p < 0.01$), their engagement ($t = 4.249$, $p < 0.01$) and their learning motivation ($t = 3.784$, $p < 0.01$) when they were exposed to the real versus the virtual characters in the authentic learning environment. Secondly, the results show that the robot, which explored and moved around the stage, provides a better sense of reality from students' feelings regarding to controlling the robot or its feedback. Thirdly, the robot facilitates higher learning motivation. Also, the preference using robots in learning in the future is higher than virtual one.

This study also attempted to investigate the influence of the RoboStage on learning performance by comparing how the student's perspective the degree of familiarity of the vocabulary with new words learned in the virtual and the mixed-reality environments. The mean of vocabulary familiarity with the ten new words learned in the RoboStage and the other ten learned in the virtual environment were calculated separately. The results of the paired simple *t*-test for the five vocabulary familiarity factors are presented in Table 4, which indicates three findings. First, overall, there was no significant difference in learning performance between learning in the mixed and virtual learning environments. Secondly, Comparing to learning with virtual robots, interacting with real robots increased the feelings of putting language in real use. Thirdly, the results regarding how much students know the meaning of the new words showed no significant difference between learning in the virtual and the mixed-reality environment. It shows that all the students have similar level of understanding of the words in the lesson. This might have resulted from the teacher's learning enhancement after the experiment.

In addition, this study analyzed the effect of two kinds of word usage. In one kind of usage, students used new words to control the robot—for example, they used the words "forward" and "west". The other kind of usage was for task completion—for example, the words "bakery" and "faint". The results of the comparison were also achieved using a paired simple *t*-test for the five vocabulary familiarity factors (as shown in Table 5). The results revealed that there was a significant difference between the results of these two kinds of word usage. Students familiarized with the words used to control the robot more than the words in the learning tasks. Learning performance was higher when students used the new words to command the robot. From the viewpoint of authentic learning, one possible explanation was that, compared to the designed learning tasks, commanding the robot to move was more like a real task for the students.

The results show that no significant difference in terms of learning new words between using virtual and mixed-reality environments. The results might lead to the fact that the short amount of usage time allotted and the lack of feedback regarding to the authentic tasks. Additionally, the students spent most of the time to control robots. Relatively little time was devoted to learning words in learning tasks. The optimal situation is that all the events are learning events and all learning events are happened in the context of the task mission. However, there may be some units that are not easy to arrange in the context properly. The responses from the robot for incorrect input were

Table 3
Learning experience with robots.

Item	SD(1)	*D*(2)	*N*(3)	*A*(4)	SA(5)
Authenticity					
I feel like what I am seeing is real when I use real objects and my voice to control the robot in the learning environment		1	7	13	15
I feel like the robot really move in the scene		1	7	10	18
The robot makes me feel that the learning activity is real		2	6	19	9
Engagement					
I would concentrate on controlling the robot to proceed with learning activities			7	11	18
I was involved in the learning activity because of the robot and the mixed-reality learning environment			11	19	6
The robot and the scene made me feel good about my learning		2	7	20	7
Learning motivation					
I like to learn English with the robot		2	8	9	17
I would use the robot to learn English for a long time		4	16	12	4
I want to use the robot to learn English again			18	6	12

Table 4
Vocabulary learning results comparing the use of the robot and that of the virtual robot.

Mixed reality–virtual reality	Paired differences					t	df	Sig. (1-tailed)
Vocabulary familiarity factors	Mean	Std. deviation	Std. error mean	95% Confidence interval of the difference				
				Lower	Upper			
Meaning	.00000	.42008	.07101	−.14430	.14430	.000	36	.500
Recall	.08571	.70174	.11862	−.32677	.15534	.723	36	.237
Experience	.26714	.95001	.16058	−.58348	.06920	1.691	36	.049*
Spelling	−.08571	.85307	.14420	−.20733	.37875	−.594	36	.277
Listening comprehension	.05714	.59125	.09994	−.26025	.14596	.572	36	.285

*Significance < .05.

Table 5
Vocabulary learning results comparing the use of control and task words.

Control words–Task words	Paired differences					t	df	Sig. (1-tailed)
Vocabulary familiarity factors	Mean	Std. deviation	Std. error mean	95% Confidence interval of the difference				
				Lower	Upper			
Meaning	.44444	1.1575	.19291	.05282	.83607	2.304	36	.013*
Recall	.30556	1.7537	.29228	−.28780	.89892	1.045	36	.151
Experience	.38889	1.1027	.18378	.01580	.76198	2.116	36	.021*
Spelling	.77778	1.3546	.22577	.31945	1.2361	3.445	36	.001*
Listening comprehension	.50000	1.0823	.18039	.13379	.86621	2.772	36	.005*

*Significance < .05.

insufficient since the robot only been designed to show an error message. It will be critical to improve authentic feedback for learning tasks not only to guide students but also to further involve them.

Besides employing questionnaires, we also observed students' behavior during the experiment. Because of the limited number of devices, only one group of students at a time allowed to proceed in the RoboStage task, we were afraid that the onlookers would feel bored. However, the learning activity involved everyone in the class. The team did the task first would collaborate with and help the other team. Some of them prepared to answer the questions, and others controlled the robot. When the robot was out of control, all team members worked together to figure out a solution that would allow them to proceed with the task. At the end of the experiment, some students indicated that, in spite of the robots' not being real humans or other living creatures, interacting with them was more interesting than interacting with virtual robots on a monitor.

4. Conclusions

Authentic learning is a modern method of learning, and students can relate target learning effectively through the concrete experience and collaborations. Additionally, authentic learning activities often consist of environments and characters (van Vugt et al., 2007). A traditional mixed-reality learning environment usually adopts synthetic agents to interact with learners. However, the sense of authenticity and the engagement that one experiences when one talks to a virtual thing is different from what one experiences when one talks to a physical thing (Andrew et al., 2007; Wainer et al., 2007; Xie et al., 2008).

Differentiating from virtual interactions, the finding positively demonstrates that the learners have a strong preference interacting with robots. The students would direct themselves speak accurately to motivate the robot around the authentic setting. Besides that, moving around the stage, using some real objects to complete the tasks makes learning more active and impressed for learners. To precede the other group in learning activity, students eagerly learn new words to achieve higher task performances. In the virtual reality mode, through the use of a keyboard and mouse to control the virtual robot, the learning activity came to simply requires students to run learning tasks that lacked a sense of authenticity.

The robot in the classroom is a practical learning partner that motivates students in learning and elicits learning performance naturally. The authentic learning platform, RoboStage, provides opportunity for students to use what they've learned in lectures or textbooks and engage them through task setting. In future implantation, we can apply RoboStage in English curriculum. We can design the context field so that most of the vocabulary can be used to command the robot. The stage can display the target learning with meaningful contexts and let students experience and practice using learned knowledge. Students can get into the RoboStage to do the assigned task with teachers' assistance. RoboStage can also be used for other courses. For example, we can develop scenarios fit to target subjects. Learners can do treasure hunting in RoboStage. Students can learn problem solving and Math by decision-making and calculating proper distance.

We expect that robots can be used to help language education in other ways as well. We also hope that this framework can inspire more educational researchers to develop more novel and interactive pedagogies and to allow children to learn foreign languages in a more natural, effective, and tension-free environment.

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