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Comparative Study on the Educational Use of Home Robots for Children

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Abstract: Human-Robot Interaction (HRI), based on already well-researched Human-Computer Interaction (HCI), has been under vigorous scrutiny since recent developments in robot technology. Robots may be more successful in establishing common ground in project-based education or foreign language learning for children than in traditional media. Backed by its strong IT environment and advances in robot technology, Korea has developed the world's first available e-Learning home robot. This has demonstrated the potential for robots to be used as a new educational media - robot-learning, referred to as 'r-Learning'. Robot technology is expected to become more interactive and user-friendly than computers. Also, robots can exhibit various forms of communication such as gestures, motions and facial expressions. This study compared the effects of non-computer based (NCB) media (using a book with audiotape) and Web-Based Instruction (WBI), with the effects of Home Robot-Assisted Learning (HRL) for children. The robot gestured and spoke in English, and children could touch its monitor if it did not recognize their voice command. Compared to other learning programs, the HRL was superior in promoting and improving children's concentration, interest, and academic achievement. In addition, the children felt that a home robot was friendlier than other types of instructional media. The HRL group had longer concentration spans than the other groups, and the p-value demonstrated a significant difference in concentration among the groups. In regard to the children's interest in learning, the HRL group showed the highest level of interest, the NCB group and the WBI group came next in order. Also, academic achievement was the highest in the HRL group, followed by the WBI group and the NCB group respectively. However, a significant difference was also found in the children's academic achievement among the groups. These results suggest that home robots are more effective as regards children's learning concentration, learning interest and academic achievement than other types of instructional media (such as: books with audiotape and WBI) for English as a foreign language.

Keywords: *Human-Computer Interaction, Human-Robot Interaction, e-Learning, Educational Media, r-Learning, Web-Based Instruction*

1. Introduction

At the start of the new millennium, the world is facing rapid changes of infrastructure led by the dramatic growth of IT, multimedia and robotics. Korea has a world class infrastructure in Information and Communication Technology (ICT) and has instigated the development of a variety of educational programs. The use of robotics in education is also on the rise, with the robot industry now recognized as one of the most important key future industries throughout the world.

Families play a vital role in educating children, and the increasingly busy schedules of many parents put high demands on time spent with their families. Parents often assist or guide children with their homework or other daily activities. With increased work pressures and a greater need and desire for leisure time, research and development (R&D) into intelligent service robots for the home is on the increase. Current trends show that R&D in robotics in Japan is mainly focused on individualized products, such as personal service robots, including humanoid robots, robotic pets, security robots and cleaning robots. In the USA, on the other hand, most of the research is controlled by the public sector, and focuses on large-scale developments, for example, projects on outdoor robot navigation in inhospitable environments, underwater robots, space exploration and robotic vehicles (World Technology Evaluation Center [WTEC] Inc., 2006). Apart from its involvement in the development of industrial robots, Korean research in robotics includes: aged-care robotic applications, humanoid robots, service and personal robots, and educational robots.

Considered to be one of the most robot-friendly countries in the world, Korea is passionately involved in research into robotics. New robots are introduced into the market every year through their active robot research programs. Recently, there has been a lot of interest in a variety of R&D research projects involving service robots. Their use can help increase

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creativity, problem-solving skills, and robot skills in children[11]. Service robots can be beneficial in many areas such as: educating people about personal hygiene, teaching important environmental issues, and helping the elderly affected by dementia.

A new companion robot, called IROBI, was recently introduced by Yujin Robotics in Korea. IROBI is both an educational and home robot, containing many features. It can teach English and tell the children nursery rhymes, entertain the family by singing and dancing, and provide home security by monitoring, detecting and photographing unwanted intruders. IROBI can move autonomously to different rooms of the house. In this study, IROBI was specifically designed and investigated for tutoring and educational services. IROBI, which has a sitting child-like appearance, is designed to support easy communication with children, Fig. 1.

Fig. 1. Child interacting with IROBI

Although the current Robot technology uses simple functions such as facial expressions on the face of a robot, gestures using arms and motions using wheels, those have been proven to make an important impact on children's learning. For instance, the research paper 'How should we look at robots?' written by Ochanomizu University and NEC showed that the face of a Robot had an important educational value by helping children to feel friendly to the Robot as an instructional medium[19]. Such a result has been supported by other studies conducted by psychologists and scholars in robotics. On this point, our research attempted to examine whether Home Robots can have educational effects although they have limited functions(i.e., change in facial expressions while talking, motions using wheels according to the situation, and simple voice recognition).

IROBI was used in this study to compare the effects of NCB media and WBI with the effects of HRL for children. The robot gestured and spoke in English, and children could touch its monitor if it did not recognize their voice command. The hands-on interaction associated with IROBI is thought to improve children's concentration, interest, and academic achievement. It is also thought to be more user-friendly than other types of instructional media. Three groups of children in the fifth and sixth grade were observed: the HRL group, the NCB group and the WBI group. Each group was presented with the same educational content, presented in a different way. The results of observation and measurements were analyzed using F-test analysis.

2. Related Work

2.1 Educational use of Robots

Computer-aided education is performed on the basis of HCI study results and various instructional design theories. Many educators believe that robotics is a suitable subject for project-based education in schools[2]. Learning through designing, building and operating robots can lead to the acquisition of knowledge and skills in high-tech electrical, mechanical, and computer engineering areas. These are high demand areas for high schools and universities, and can promote the development of thinking, problem solving, self-regulation and teamwork skills[4].

In the USA, an autonomous robotics course has already been created out of research, ongoing since 1990, in assembly and programming languages. The course was developed at MIT, first for K-12 education and later for an undergraduate course[3], and three courses on autonomous robotics are offered at the University of Washington[4]. Building and programming robots is an interesting and inviting prospect to students. A study was conducted into the implementation of robot control learning via programming with the RB5X, a programmable robot developed in the 1980's and used for teaching. The research in elementary and secondary schools and universities over six months, resulted in findings that it was very effective for children's learning in mathematics (See http://www.edurobot.com).

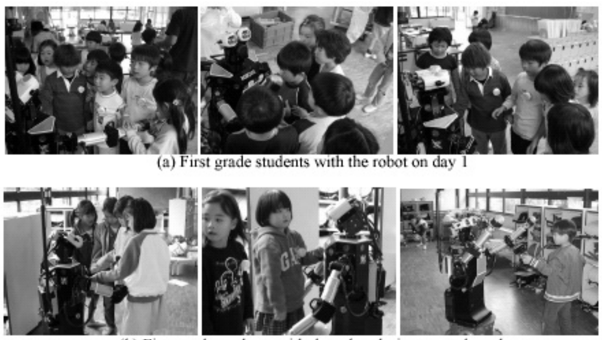
In Britain, various events are held on the educational use of robots. These include autism treatment and a waste minimization and recycling campaign aimed at school children[9]. Price et al (2003) stated that Lego-based robotics is very absorbing and enjoyable for many children and adults. Hirst et al (2002) investigated the best environment-language for teaching robotics using Lego. There are other studies on assembling and programming robots by using Lego's Mindstorm kits for teaching science and technology in Sweden, Denmark, and other countries [16, 17].

On the other hand, learning with robots has been more successful when children already have some initial proficiency or interest in English. Studies on robot-aided education are still relatively new and most are in the early stages in a starting phase. Therefore, attempts need to be made to use robots for educational purposes and to investigate the effects of their use in this field.

In Japan, the educational use of robots has been studied mostly with Robovie in elementary schools focusing on English language learning. ROBOVIE has behavior episodes with some English dialogues based on 800 rules in memory. To identify the effects of a robot in English language learning, Kanda et al (2004) placed a robot in the first grade and sixth grade classrooms of an elementary school for two weeks, and compared the frequency of students' interaction with the English test score, Fig. 2. Although the two-week robot-aided learning did not provide any significant effect on the students' test score in English speaking and listening, the students who showed a lot of interest at the starting phase had a significantly elevated English score. This implies that robot-aided English learning can be effective for students' motivation.

Canada also uses robots for health and hygiene education in schools. Kohlhepp (2003) reported on the use of a life-size, interactive robot, known as the "Caring Coach", to teach children fitness and healthy living. It has been used in 43 districts including Livingston Park and North Brunswick, and has helped educate nearly 2,259,000 children over 12 years.

Korea has a strong IT framework, a rapidly growing e-learning industry, an abundance of potential users, and a robust robot technology industry. These are the four elements essential for the development of intelligent robots which can incorporate e-learning. In consideration of the potential of such a framework, a Korean robotics company recently announced the release of its internet-based family robot. The educational service robots are embedded with a number of e-Learning functions as well as other household services. Fig. 3 shows the home tutor robot, IROBI, and the teaching assistant robot, TIRO[10]. But there is no study on the effect of the educational service home robots embedded with e-Learning materials.



(a) First grade students with the robot on day 1

(b) First grade students with the robot during second week

Fig. 2. ROBOVIE interacting with Children in Primary School

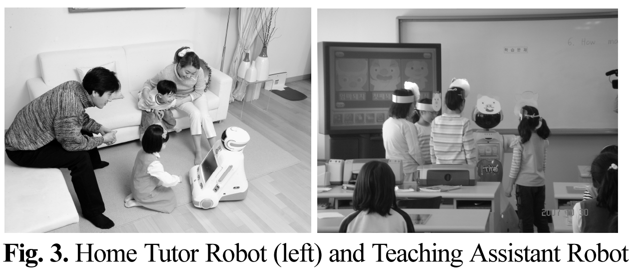


Fig. 3. Home Tutor Robot (left) and Teaching Assistant Robot (right)

2.2 Designing Content based on HRI in HCI

There has been extensive research in HCI, the study of interaction between computers and users, dating back for nearly 30 years. Demonstrating its usability and usefulness, the development of the early graphical user interface (GUI) of the Apple Macintosh was followed by the hugely successful Microsoft Windows, both of which have had an enormous impact on everyday computing. With the growth and development of the intelligent robot market, HRI is a relatively new area compared with Human-Machine Interaction (HMI) and HCI. Experts believe that we are now living in the "post-PC era".

Kiesler and Hinds (2004) argue that HRI should be based on HCI; that it offers rich resources for research; and autonomous robots are a distinctive case for several reasons. These include the facts that robots are: Often perceived by humans as humanoid or similar to themselves, Usually mobile, Capable of decision making.

Fong, Thorpe and Bauer (2001) addressed the difference between HCI and HRI as shown in Table 1. They believe the major components of HRI to be a man, a robot and a system.

Table 1. Comparison between HCI and HRI

HCI	HRI
Controlled by men	Autonomy
2 dimensions	3 dimensions
Simple	Complex
Static User Model	Dynamic User Model
Fixed or Portable	Movable
Mostly, vision & audio	Vision, Audio, and Tangibleness
	Face to face
	Learning and Decision

Thrun (2004) believes that one of the major factors in HRI is autonomy. Also, Scholtz (2003) argues that HRI requires a different evaluation model to those in HCI or HMI, and proposes five roles of interaction (i.e. supervisor, operator, mechanic, peer and bystander) in HRI by applying Norman's (1986) HCI model to take account of mixed, dynamic and self-motivating characteristics of a robot. We consider that it is important to understand the difference between HCI and HRI for designing e-Learning contents of educational robots.

2.3 e-Learning and Robots

e-Learning is expected to revolutionize the existing educational environment by adapting various ICTs beneficial to education, sharing of abundant information and knowledge, use of various human resources, easy interaction, use of multimedia-type information, easy development and maintenance of contents, and just-in-time education[6].

The typology of e-Learning could be helpful in exploring the creative use of IT, HCI and robotics. From case studies, the educational use of e-Learning can be divided into the following five types[1]:

- Sharing and Use of Online Information: new content can be instructed just-in-time as a variety of information is appended from time to time.
- Use of Human Resources: one's opinions and materials are exchanged on and off with friends, teachers and professionals in various fields.
- Construction of a Learning Community: synchronous and asynchronous interaction, in one-to-one, one-to-many, and many-to-many manner can be carried out for information exchange and inter-cooperative activities.
- Easy Use of Analysis Tools and Materials: various types of raw data such as statistics and scientific experiment results are provided, and data analysis and mutual comparison of the analysis results can be easily conducted.
- Production of Information and Open to the Public: new information can be produced in the process of exploring specific topics or validating a hypothesis. Also the results can be stored in a database system and made open to the public.

Many past attempts to use new media for educational purposes have failed because the media was simply used as a means to improve traditional instructional methods, within the old educational paradigm, and because only the technical side of the media was emphasized with little or no consideration of providing media specific education programs and learner support. Likewise, in attempting to use robots for educational purposes, without careful consideration of educational needs and the characteristics of robots, the attempt may result in providing merely a novelty effect. Therefore, the following list of options should be taken into account in designing and implementing e-Learning contents[5,6]:

- Provide various options to learners throughout the entire process of learning
- Provide high quality content in various forms of multimedia materials
- Realize just-in-time education in order to use up-to-date information
- Thoroughly supervise one's learning including management and reporting of learning progress and accumulated learning accomplishments
- Support learner's reflective activities on the process and outcomes of learning
- Encourage community vitalization to promote various learner-centered interaction
- Provide a best-fit learning environment to extend self-regulated learning ability
- Build a learning network to effectively support human resource
- Provide an environment that can meet learners' various needs

Four educational goals using robots were identified: integration of a range of knowledge, study of real-world issues, interdisciplinary team-work, and enhancement of critical thinking[3]. When embedding e-Learning functions in robots, it is essential to study various instructional methods that will guide students and allow self-regulated and interactive learning with robots.

The content of e-Learning robots is expected to be more interactive with humans and more user-friendly than computers. It will also allow for various forms of expression such as gestures, motions and facial expression[23]. Table 2 shows a comparison between computer-based and robot-based contents in regard to input, output and interaction. Our robot-based contents in Chapter 3 have voice and touch screen(LCD panel) input without face and gesture recognition.

3. A Home Robot for e-Learning

3.1 Introduction on IROBI and Storyboard

In this study, IROBI was specifically designed and

Table 2. Comparisons between Computer and Robot Contents

	Computer-based Contents	Robot-based Contents
Interaction	Static, Restrictive	Dynamic, User-friendly
Input	Mostly: Mouse, Keyboard	Voice, Face, Touch Screen, Gesture, Sensing
Output to human	Audio, Animation, Moving	Audio, Video, Animation, Voice, Gesture, Facial Expression

investigated for tutoring and educational services. IROBI, which has a sitting child-like appearance, is designed with an LCD panel on its chest to support easy communication with children. It has various sensors, such as vision on its head, sense of touch on its LCD chest panel and audio sensors on its ears. It has various facial expressions, which include smiling, angry, sad, joyful and others. At 65cm tall, IROBI's size is important for interaction with children. IROBI has a head (3 degrees-of-freedom or DOF), two arms (shoulders have 1 DOF and elbow joints are fixed), two LED eyes (8 by 8 dot matrix) lips, and a mobile platform (8 wheels). IROBI can generate behaviors such as singing, talking and dancing (left and right turning, forward and backward moving) required for communication with children. The operating system of IROBI is Windows XP. The specifications of IROBI are shown in Table 3 below.

Table 3. Specifications for IROBI

ITEM	CONTENTS
CPU	VIA C3 800 MHz
RAM/HDD	256 Mbytes/30 Gbytes
LCD	TFT Color 12.1"
CAM	33K pixel CMOS camera
LAN	Wireless Lan 10Mbps
Audio	Stereo 2CH(7.5w *2)
Size	650(H) * 430(W) * 480(D)mm
Weight	15kg
Speed	Maximum 25cm/sec
Sensor	Human sensing, Ultrasonic, Bumper, Floor Detection

We developed the robot contents, 'At a library', 'Oops! Fish here!' and 'Flying away'. The robot contents are designed to have voice and touch screen input without face and gesture recognition. A storyboard example 'At a library' of IROBI's educational content is shown in Figure 4. The list of contents is displayed on the LCD panel. When a learner(child) shouts "At a library, Let's go!", then IROBI reads the episode aloud. When IROBI finish reading, IROBI enters into conversation with the learner by shouting "Now, we start to exercise the dialog. You are Tommy, I am Daddy. Let's start! Umm!". Also IROBI requires a learner to follow the instruction and pronounce 'Daddy, I'm going to look at the books'.

The factors in the storyboard of IROBI's english content are face-to-face interaction and communication through speaking and touching unlike computers(See Fig. 4). Children can use IROBI to perform their learning tasks by giving voice-controlled commands or touching its touch screen when voice commands are not recognized.

3.2 Development of Robot's Contents

IROBI's contents for learning English were developed using an authoring tool called 'eR-Author' of Yujin robotics Inc. The features of eR-Author allow users to easily create and edit interactions between users and robots (i.e. HRI components-GUI, support for voice recognition and synthesis), and includes a 3D simulator. The authoring tool controls the patterns of HRI components described above the storyboard as object blocks, which can be inserted, deleted and dragged into its timelines. Also, the parameters of the patterns can be easily edited. As shown in Fig. 5, eR-Author consists of

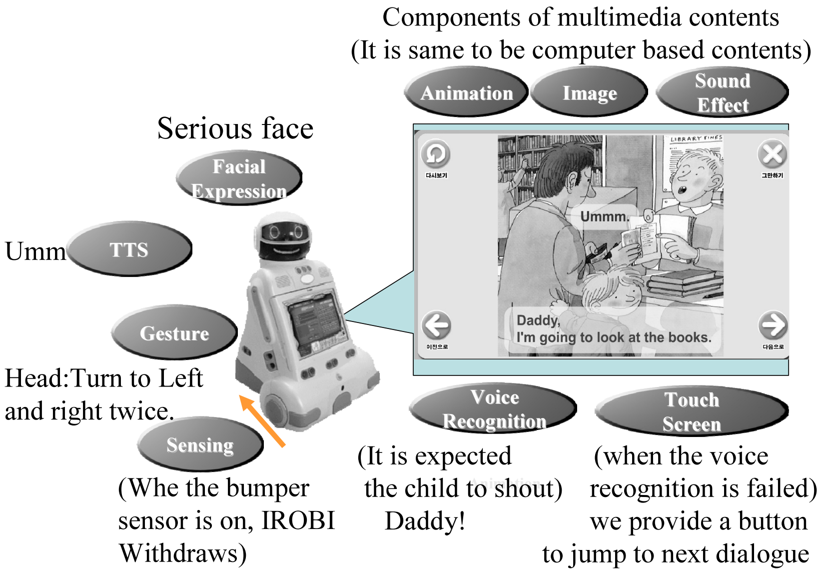


Fig. 4. Factors in the Storyboard of IROBI's English Content

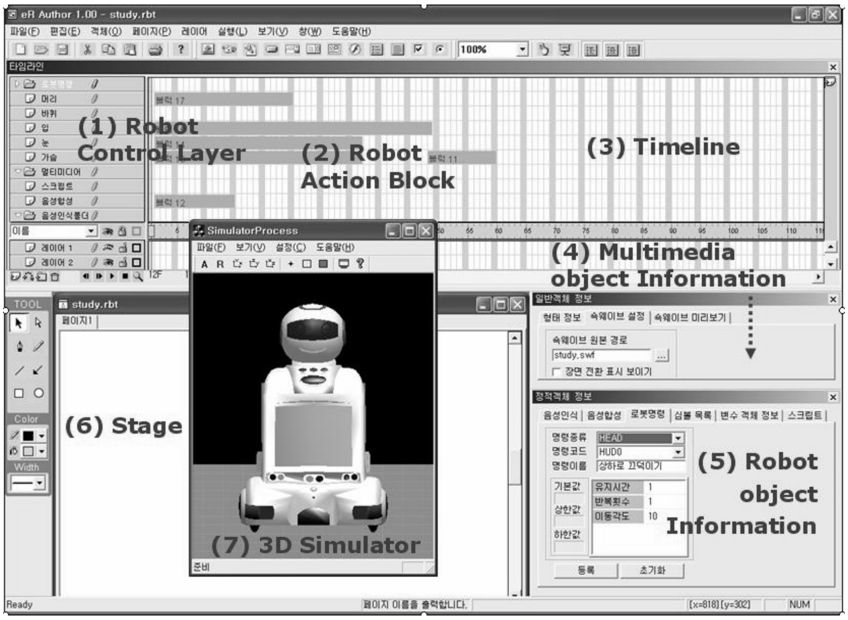


Fig. 5. Screenshot of Authoring Tool used for IROBI

(1) robot control layer, (2) robot action block, (3) timeline, (4) multimedia object information, (5) robot object information, (6) stage, and (7) 3D simulator[22].

The robot control layers include head action, wheel action, eye LED, heart LED and mouth LED, layered respectively. Specific robot action blocks should be placed in each layer. The robot action information dialog shows parameters for robot action blocks, and the multimedia object information dialog contains details of multimedia objects. Multimedia objects such as Flash files, SWF, are displayed visually in the stage window. Once all the action blocks and multimedia objects are set in place, the result can be previewed (screen and robot gestures) in the simulator. The simulator shows virtual 3D rendering and motions of IROBI in a realistic manner. To play the robot contents made by eR-Author, eR-Player must be installed on the robot side. eR-Player is a software module running in the robot. It executes physical user-robot interaction, downloads e-contents from content servers, and displays the contents on the LCD panel.

4. Educational Effects of Home Robots

Fumihide et al. (2007) conducted an experiment in which very young children, or toddlers, were exposed to a social robot in a preschool classroom. At first, the children treated the robot differently than they treated each other. But after some months, the robot had become part of their class, and they were treating it as one of their own. Children responded well to various types of stimulation and interaction in educational environments, and they also responded to familiar and friendly entities, such as IROBI.

4.1 Hypothesis

The effects of interaction between children and home robots were examined on children's interest, concentration and achievement in English learning, and compared with the effects of other instructional media. From the comparison, the significance of a home robot as a learning tool was investigated. The hypothesis of the study was focused on the classic HCI usability evaluation factors (ISO 92411-11), that is: efficiency, effectiveness and user satisfaction[22].

- **Hypothesis 1:** Home robots make no difference in the effects on children's concentration in English learning.
- **Hypothesis 2:** Home robots make no difference in the effects on children's interest in English learning.
- **Hypothesis 3:** Home robots make no difference in the effects on children's accomplishment in English learning.

4.2 Experimental Design

We designed to present an English dialogue to be played for about 40 minutes for fifth to sixth graders, and developed the PC based contents, 'At a library', 'Oops! Fish here!', and 'Flying away'. Then we made a color text book of hardcopies and recorded the voice to a cassette tape. Also, the same content on a PC monitor for the WBI group is delivered to a monitor placed on the chest of a robot for the HRL group. We added robot action scripts into the robot based content for HRL group.

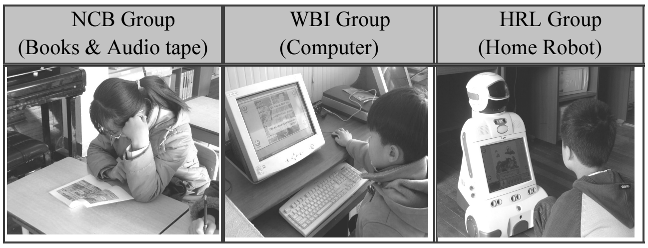


Fig. 6. The experimental scenes

Observation, questionnaires, interviews and a test of proficiency in English were conducted in order to examine the learning effects of home robots on children. The focus was on children's interest in learning, concentration and academic achievement. A comparison was also made between the effect of using home robots and other instructional media such as NCB and WBI.

The subjects, 90 children of similar academic level, were divided into three groups: the HRL group, the NCB group and the WBI group. Each group consisted of 15 boys and 15 girls in the fifth and sixth grade. Each group was presented with the same English content, but in a different way following the instructional method assigned to each group as shown in Fig. 6.

The experiments with the NCB and WBI groups were carried out first and were followed by the experiments with the HRL group. This was done in order to prevent the other media experimental groups from feeling any sense of deprival or envy towards the HRL experimental group, which could distress the children and possibly affect the outcome. In addition, the HRL experiment was well controlled in terms of time and space. All subjects were told not to talk about the experiment before or after. They were not informed in advance of the scheduled academic achievement exam so that they could perform the experiments with no psychological burden. In order to minimize the novelty effect, the subjects in the HRL group were encouraged to do as much interaction as they wanted for a few days before the start of the experiments.

The concentration of the subjects in every group was observed at 10 minute intervals, with the four scaled score ranging from 4-point, 'very active interaction-concentrating all the time' to 1-point, 'no concentration and no interaction-being on a loose pulley' for testing Hypothesis 1 by researcher's subjective.

When the learning activity was completed, the subjects were surveyed about their interest in English learning using a five-point scale questionnaire for testing Hypothesis 2. One day later, all the groups were asked to take a test in order to examine their achievement in English learning for testing Hypothesis 3. The test consists of 20 questions, which 7 questions are related to our English content.

4.3 Results

The average scores of concentration behaviors for Hypothesis 1 are presented in Fig. 7 as observed in each experimental group. The HRL group remained stable and at a high level in learning activities as time passed. The NCB group and the WBI group gradually reduced their learning-relevant behaviors. In particular, the NCB group was observed to often make demonstrated passive behaviors such as nodding,

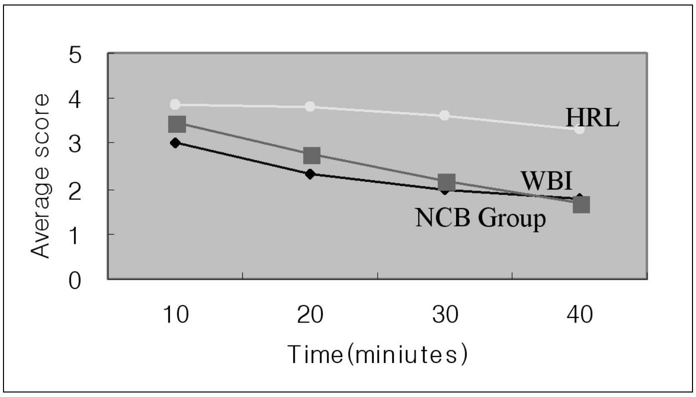


Fig. 7. Trends of Concentration Behaviors for each group

Table 4. Average score of instructional effects for each group

Type of media / Factor	NCB Group	WBI Group	HRL Group	F(2,87)	p-value
Concentration (4-point scale)	2.23 (0.56)	2.52 (0.76)	3.66 (0.33)	19.5047	.0000***
Interest (5-point scale)	3.4 (0.72)	3.57 (0.82)	4.47 (0.68)	17.891	.0000***
Achievement (7 problems)	4.61 (1.37)	4.80 (1.09)	5.50 (1.13)	4.5081	.0137*

Note: (standard deviation), *** denotes p-value<0.001, ** denotes p-value<0.01, * denotes p-value<0.05

turning the pages without paying attention to the book, and listening without looking at the book. The WBI group was active in the starting phase of learning, but within 30 minutes, became distracted and gradually more passive in their actions. Compared to these two groups, the HRL group performed best in learning concentration.

The results of observation and measurements were analyzed using the F-test with the group average as shown in Table 4.

According to the results, the scores on the three factors of concentration, interest and achievement, were significantly higher and steadier in the HRL group than the other media groups. Concerning Hypothesis 1, significant differences among the groups were found by p-value 0.00 ($F(2,87) = 19.5$), and the duration of concentration in the HRL group was the highest. Concerning Hypothesis 2, the differences among the groups were found to be significant by p-value 0.00 ($F(2,87) = 17.89$). From the five-point scale questionnaire, the HRL group showed the highest level of interest, followed by the NCB group and then the WBI group. Finally, concerning Hypothesis 3, significant differences among the groups were found in the subjects' academic achievement by p-value 0.01 ($F(2,87)=4.51$). The academic achievement was the highest in the HRL group, followed by the WBI group and then the NCB group.

These results suggest in the short view that the use of home robots in children's learning is more effective for their concentration, learning interest, and academic achievement than the other two types of instructional media (books with audiotape and WBI) in the domain of English as a foreign language. It is needed to investigate the effect on the educational robots in the long term for the future work.

5. Conclusion

Robots are expected to provide improved interaction with humans and be more user-friendly than computers. They can also offer various forms of expression such as gestures, motions and numerous facial expressions. With these positive characteristics of robots in mind, our research team attempted to investigate the prospects of robots as a new educational medium.

In this research, the effect of robots on children's learning has been investigated. A comparison was made among the effects of traditional media (books with audiotape-assisted learning and WBI) and the effects of home robot-assisted learning for children. Compared to the other learning programs, NCB and WBI, the home robot was significantly superior in promoting and improving children's concentration, interest and academic achievement for English as a foreign language. This suggests that the home robot as a tutor for children is most useful and could become a new educational media. These results have demonstrated the potential of home robots as effective tutors for children.

Future research will include an expansion of these experiments to other areas of study by changing the robot e-learning contents, and observing the differences in children's attitudes to learning in the long term.

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