A JOYFUL CLASSROOM LEARNING SYSTEM WITH ROBOT LEARNING COMPANION FOR CHILDREN TO LEARN MATHEMATICS MULTIPLICATION

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ABSTRACT
This research demonstrates the design of a Joyful Classroom Learning System (JCLS) with flexible, mobile and joyful features. The theoretical foundations of this research include the experiential learning theory, constructivist learning theory and joyful learning. The developed JCLS consists of the robot learning companion (RLC), sensing input device, mobile computation unit, mobile display device, wireless local network and operating software. The aim of this research is to design and evaluate the JCLS, which is implemented by using robot and RFID technologies. The developed JCLS system has been applied in real world for supporting children to learn mathematical multiplication. Both pilot experiment and formal experiment were conducted and the results showed that the JCLS can provide learners with more opportunities for hands-on exercises and deepening their impressions about the learning contents. Having many opportunities for hands-on exercises, learners can have more thinking time for knowledge construction. Using robot to design RLC can simultaneously increase learners' motivations and offer a more joyful perception to learners during the learning process. On the other hand, the JCLS can support instructors to immediately acquire the learning statuses of every learner for adjusting his/her in-class instructional strategy and giving after-school assistances.

INTRODUCTION
Washburne (1936) defined learning as a process of acquiring knowledge, technique, attitude and value through instruction and experience. Human intelligence development is affected by the inborn conditions and acquired contexts since childhood. The development process contains several steps, and the time required for reaching each step is different for each individual learner because each previous step is the foundation for the next step and the sequence is successive (Flavell, 1963; Piaget, 1970). Therefore, a suitable learning environment with proper learning sequence is essential for learning, especially for children who are still in the early development period. Besides, researchers have also emphasized the importance of joyful learning for children in recent years (Fisher, 1998; Heywood, 2005). With nowadays newly invented technologies like educational robot and RFID make technology enhanced learning a promising solution for assisting children learners.

Theoretical foundations
The theoretical foundations of this research are the experiential learning theory, constructivist learning theory and joyful learning. The core concept of experiential learning theory (ELT) is that instructors should draw learners' attention on their real-life experience while conducting experiential learning. Experiential learning follows four different steps including concrete experience, reflective observation, abstract conceptualization and active experimentation (Appelman, 2004; Kolb, 1984). It is a repeated cycle for the continuous experience and exploration (Kolb & Kolb, 2005). ELT also suggests that children would get a stronger impression about things if they could touch and manipulate tangible objects such as learning by doing. For example, learning by doing with sufficient practice time for learners was the predominant strategy as it is found to have positive effects for learning and knowledge construction (Appelman, 2004; Bruckman, 1998; Cronjé, 2006; Dewey, 1938; Kolb & Kolb, 2005; Piaget, 1968). Some practical examples are like BioHazard about environmental science (http://www.educationarcade.org/gtt/biohazard/Intro.htm), La Jungla de Optica about optical Physics (http://www.educationarcade.org/gtt/Jungle/Intro.htm), Daedalus'End about civil engineering and engineering ethics (http://www.educationarcade.org/gtt/Globalization/Intro.htm), and Quest Atlantis about language arts, mathematics, and social studies in a multi-user 3-D virtual environment (Barab, Thomas, Dodge, Carteaux, &

Tuzun, 2005).

Equal opportunities provided to learners for engaging learning activities in a learning environment are also necessary and important (Cheng, Wu, Liao, & Chan, 2009). Acquiring stronger impressions through the hands-on experiences have a great potential to contribute in knowledge construction and comprehensions. As suggested by constructivist learning theory (CLT) that knowledge cannot be directly supplied by instructors or others, but has to be created by learners themselves (Bruckman, 1998; Cronjé, 2006; Piaget, 1968). Some practical examples are like the players learn through iterative design processes, observing how the robot works, and modifying the robot design (http://www.educationarcade.org/gtt/hephaestus/Intro.htm). Instructors play the role of an organizer, facilitator and resource provider to help learners in their learning process. Learners can concentrate on acquiring knowledge, skills and values through repeated self-thinking exercises in a well-designed learning environment based on ELT and CLT (Dewey, 1938).

Joy, according to the Oxford English dictionary, is described as a vivid emotion/feeling of pleasure. The adjective of joy is joyful which also describes a kind of feeling, expressing and causes great pleasure. In this research, we define the "joyful learning" as a kind of learning process or experience which could make learners feel pleasure in a learning scenario/process. A joyful perception is found to have positive influence on the motivation of learning (Chen, Chen, & Liu, 2010; Kirikkaya, İşeri, & Vurkaya, 2010). A number of modern educational games with joyful learning features are being developed by various researchers based on pedagogical theories and strategies (Chen & Tsai, 2009; Kebritchi & Hirumi, 2008).

Instruction and learning perspectives

The two main perspectives, namely learning and instruction, are included in this research. From the learning perspective, learners' problem solving abilities are very important and could be cultivated through adopting appropriate pedagogies in learning processes. How to cultivate problem solving ability is very critical during childhood while a learner is beginning to learn and receive instruction. Therefore, from the learning perspective while designing the JCLS, the goal is to train and cultivate learners' problem solving abilities (Lindh & Holgersson, 2007; Tsai, Chen, & Chen, 2010).

From the instruction perspective, if instructors simply use oral lectures to explain learning materials, sometime learners are not able to comprehend the meaning. In such a situation, instructors can use physical objects or tangible tools for providing learning help. For example, instructors could utilize physical learning materials to enhance learners' realization about learning contents. However, the problem is that how could an instructor acquire the real-time progress status of each individual learner so as to provide instant help. This is particular difficult in conventional learning environments without any information and communication technology (ICT) support. The ICT advancements have made technology enhanced learning (Chen, Lin, & Kinshuk, 2008; Schiaffino, Garcia, & Amandi, 2008) and mobile learning (Huang, Kuo, Lin, & Cheng, 2008; Motiwalla, 2007) more and more popular in our educational settings.

Robot-related applications in educational field

Due to the rapid developments of new technologies, educational researchers can now apply various ICT tools in practical scenarios to enhance learning experiences and performances of learners such as multimedia, interactive white board, smartphone, and robot. In February 2010, Ministry of Education in South Korea announced that they will equip robots for all 8,400 domestic kindergartens to facilitate instruction by 2013. Educational researchers evidence that the robot as an instructional assistant or a learning companion can enhance learners' learning motivation and learning performance (Barker & Ansorge, 2007; Chen, Hung, Lee, & Wei, 2010; Chung, et al., 2010; Fasola & Mataric, 2010; Johnson, 2003; Klassner & Anderson, 2003; Mitnik, Recabarren, Nussbaum, & Soto, 2009; Ruiz-del-Solar & Aviles, 2004). Furthermore, using robot as an instructional assistant or a learning companion, can also enable instructors to provide learning content which facilitating learners to interact with real objects through navigating digital learning content (Jermann, Soller, & Mühlenbrock, 2001). For example, while learners are learning physics, the robot can utilize its capabilities, including rotation, mobility, and acceleration, to explain the Newton's laws of motion (Mitnik, Nussbaum, & Soto, 2008).

In the near future, school-age children are predicted to have educational robots accompanying them in the learning process and assisting them in comprehending the learning materials (Jones, Jo, & Han, 2006). Before discussing robot applications in educational field, it would be important to analyze the types of robots in general. This research categorizes robots into three types according to the purpose of their original design, namely (a) pure toy, (b) education and recreation, and (c) purpose on-demand robot. The comparisons of these three types of robots are described in Table 1.

Table 1: Types and functionalities of robots

Utilities	Types		
	Pure Toy	**Education and Recreation**	**Purpose on Demand**
Application Domain	Entertainment	Education and Entertainment	Scientific Research & Special Scenarios
Form	Humanoid, Animal, Vehicle form	Humanoid, Animal, Biped, Vehicle form	Various / Multiform
Movement	Walk, Crawl, Fly	Walk, Crawl, Fly	Walk, Crawl, Fly, Special type
Multimedia Function	Piezo Buzzer, Speaker, Mono LCD	Piezo Buzzer, Speaker, Mono LCD	Piezo Buzzer, Speaker, Mono / Color LCD
Sensor / Plug-in Module	Infar Ray(IR), Sound, Touch, Acceleration	IR, Light, Sound, Touch, Acceleration	IR, Light, Sound, Touch, Video, Acceleration, GPS, Text-to-Speech…
Number of Joints	Few	Normal	Many
Control Method	IR, Build-in Controller	Cable, IR, Bluetooth, Zigbee	Cable, IR, Bluetooth, Zigbee, Wi-Fi…
Re-Assemble Level	Low	Normal	High
Re-Programming Level	Low (build-in function)	Normal	High
Price Range	USD$ 50~1500	USD$ 100~2000	USD$ 5000~300000 or more expensive
Some Manufacturer	Wowwee, SONY, Kondo, Bandai	LEGO	MOBILEROBOTS

The first type pure toy is a generic robot that is commonly treated as simply playing for fun. This type of robots is originally designed for entertainment, and therefore they do not have many complex functions or reconfigurable capabilities. But, it is possible to use them in a conventional physical classroom for assisting instruction by designing suitable learning activities, for example, Wowwee's Spain series (You, Shen, Chang, Liu, & Chen, 2006) and Sony's AIBO robot dog (Francis & Mishra, 2009). The second type of robots is designed dedicated for education and recreation such as the widely known LEGO MINDSTORMS series. Various schools nowadays are using this type of robots for training and stimulating logical thinking abilities of pupils through assembling the robots with LEGO bricks and programming them in the visual programming systems (VPS), for examples LEGO's ROBOLAB software or some other third-party products (Jarvinen, 1998; Lindh & Holgersson, 2007). Some researchers have focused on designing agent-based systems to assist instructors in monitoring learners' learning status by using robots (Zhang, Kinshuk, Jormannainen, & Sutinen, 2008). The third type of robots, purpose on demand (POD), is designed for specific research, industrial use or other particular purposes. Their powerful hardware, complex functions, and flexible configurations make them very useful for advanced applications.

Research objectives and questions

The aim of this research is to design and evaluate a JCLS by using RLC and RFID technologies. The designed system can be used in three different learning scenarios including conventional physical classroom teaching, classroom group collaborative learning and self-paced learning at home by supporting three application modes, namely instruction, collaborative learning and self-learning.

A prototype has been designed for a Joyful Classroom Learning System (JCLS) in this research to support children's learning in mathematics. The JCLS is designed and implemented using robot learning companion (RLC) and Radio-Frequency IDentification (RFID) technologies. The RLC has a tangible body with several intellectual actions that are useful in a learning process and could bring joyful perceptions to the learners. The RFID technologies could help learners to simplified data input especially for little children who are not familiar with QWERTY keyboard.

After designed and implemented the Joyful Classroom Learning System (JCLS), the evaluation of the system was conducted with respect to the two questions. (a) Can the designed JCLS help children learners to have better learning experiences in terms of experiential learning, constructivist learning and joyful learning? (b) How do children learners perceive the usefulness and ease of use of the JCLS?

Design and Implementation of a Joyful Classroom Learning System (JCLS)

Key hardware components

Robot learning companion, sensing input devices, mobile computation unit, mobile display devices and wireless local network construct the whole hardware components of the designed JCLS. These five components are essentially required for designing different learning scenarios in the JCLS. To choose suitable devices for these five components depend on the designed learning activities and available products in the market. A survey has been done on commonly used products and their main functions which can be used for these five components as shown in Table 2.

The RLC can attract learners' attentions resulting in improved motivation for learning. In this research, the LEGO MINDSTORMS NXT is adopted to be the robot learning companion and mobile display device. The RFID is used as the sensing input device. The mobility of the computation unit is crucial as it enables children learners to move around the classroom while doing group collaborative learning. The designed JCLS currently adopts Wi-Fi to build a wireless local network for information exchange among interconnected devices. Of course, other wireless local network technologies such as ZigBee (Morais, et al., 2008) and GroupNet (Chen, Kinshuk, Wei, & Yang, 2008) can also be used as a solution if they become cheaper and more popular.

Table 2: Five main components and potential devices to be used for designing a JCLS

Element	Example	Function
Robot learning companion	LEGO MINDSTORMS NXT*, Wowwee Robosapien, and Aldebaran Robotics Nao	Interaction
Sensing input device	Barcode, RFID*, QR Code, Electronic pen, and Laser projector keyboard	Input
Mobile computation unit	Laptop*, OLPC, Netbook, PDA, Smartphone, iPhone and iPad	Processing and storage
Mobile display device	Embedded display in the RLC*, Portable projector, Touch screen, Electronic paper, and Eye screen	Output
Wireless local network	Bluetooth, Wi-Fi*, ZigBee, and GroupNet	Data exchange

Note: * represents the option used in this research

Application modes

Three application modes were designed for the JCLS. The first mode is called instruction mode (Figure 1(a)). Every learner is provided with a RLC that enables all learners to have an "equal opportunity" to participate in the classroom learning activities guided by the instructor. Every learner in the JCLS can directly interact with his/her RLC for a better engagement in the learning process, compared to the traditional sit-and-listen leaning environment. An instructor can use the instruction mode to quickly deploy learning materials to learners in the class. In the meantime, the system will be automatically logging and sorting the learning status of every learner throughout the learning activity. This feature enables an instructor to view the summary of important information about learners making it possible for the instructor to provide timely assistance to the learners. Furthermore, since the JCLS has recorded complete logs of every learner, a deeper analysis of the learning patterns for each individual learner is also possible, making it easier for an instructor to better understand the obstacles experienced by any individual learner during the learning process. Based on such analysis, the instructor has the possibility to provide adaptive instruction to each individual learner.

The second mode is called collaborative learning mode (Figure 1(b)). The JCLS provides a grouping mechanism to support collaborative learning. Learners can be grouped into several teams for carrying out collaborative learning activities. The features of flexibility, mobility, and joyfulness can be included for collaborative learning activities in the JCLS, for achieving more positive effects in the learning process. Once learning activities are being designed, the JCLS can act accordingly to guide learners going through the collaborative learning process without instructor's intervention. That is to say instructors play the role of facilitators whereby an unforeseen situations occurs, they can then provide appropriate assistance if necessary. The JCLS keeps the instructors with updated information about each team's progress in order to ensure that the goals of the learning activities are finally achieved.

The third mode is called self-learning mode (Figure 1(c)). This mode provides a useful and friendly way for a learner to preview or review learning contents. The functionality of the JCLS in this mode is much simpler, and it only focuses on providing suitable learning content to the learner based on the built-in learning materials database, making the learning process more effective for the individual learners. Learners however, also have the opportunities to request the learning content according to their own preferences. The role of RLC here acts like an accompanying tutor who could give a learner timely feedback and guidance making self-learning less feeling of learning alone.

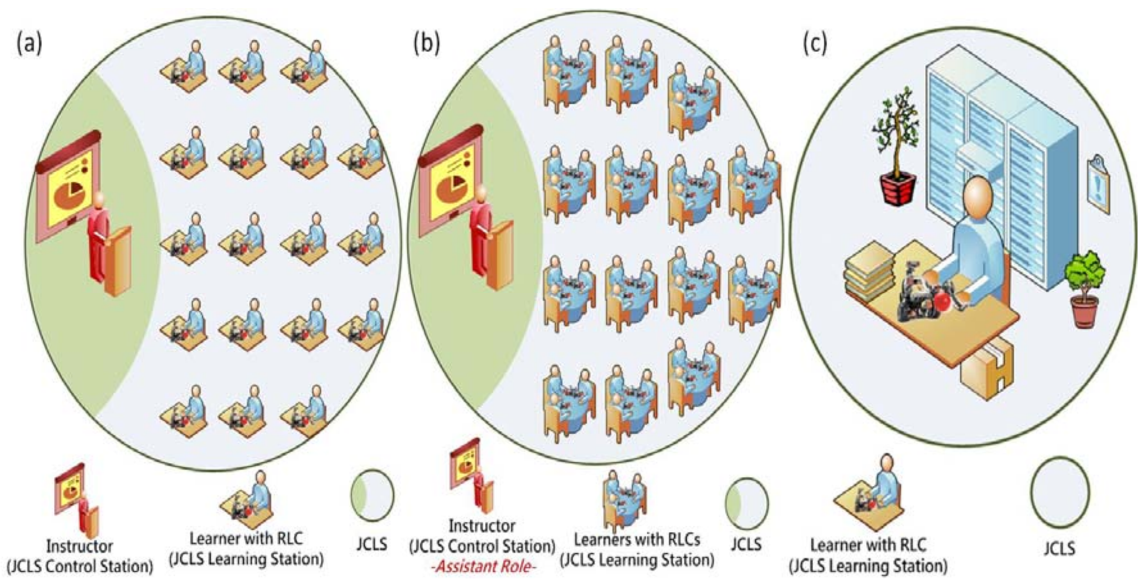

Figure 1: The three application modes of JCLS: (a) Instruction; (b) Collaborative learning; (c) Self-learning

The implementation of joyful classroom learning system (JCLS)
As shown in Figure 2(a), the JCLS furnishes every learner with a "learning station" comprising of robot learning companion (RLC), sensing input device, mobile computation unit, mobile display device, wireless local network and the operating software. In practice, the learning station consists of a LEGO MINDSTORMS NXT, a laptop, an RFID reader, learning materials with RFID tags, and operating software for learners. Regardless of which application mode the learners are currently in, they interact directly with the RLC while engaging in learning activities by using a more intuitive method of RFID tags as inputs rather than a traditional keyboard typing. On the other hand, the instructor has a control station comprising of mobile computation unit, mobile display device, wireless local network, and the operating software.

The architecture of the JCLS can be subdivided into two parts, hardware and software. In a typical scenario for the instruction mode, the control station and all learning stations are interconnected through Wi-Fi network connection as shown in Figure 2(b). RLCs and RFID readers are connected to learners' learning stations. The RFID tags are attached to the physical learning materials and given to the learners. The information of the learning material stored in RFID tags is retrieved by the RFID reader. Depending on what information is received through RFID tags, the system then triggers RLCs to make some actions, show some brief information on their screens, and utter corresponding sound as feedback to learners. The JCLS operating software equips with two agents, namely control agent and coordination agent, and five modules, namely notification, sound effect, motion, instruction and presentation. Coordination agent is in charge of the initiation of these five modules depending on the application mode and for starting the networking in order to facilitate information exchange. Next, the control agent takes over the follow-up operations for the activated modules.

The logical flow of the instructional mode is shown in Figure 3. In the beginning, the coordination agent senses that the instruction mode has been activated and starts the networking for information exchange. Next, it initiates all the five modules and informs the control agent to take over the follow-up operations. The JCLS runs on both the control station (Figure 4(a)) and the learning station (Figure 4(b)). Instruction, notification and presentation modules are then enabled at the control station which used by the instructor. All learning stations remains under the instructor's control in order to provide the learner with related learning materials and guidance during the learning process. Various learning activities can be accomplished by interacting with the RLCs and using RFID tags. Furthermore, notification module is enabled at the control station in order for the instructor to monitor all actions taken by learners at all learning stations. The control station provides three main functions for instruction. Firstly, it handles the switching of the application mode in order to enable correct mode to align with the current learning scenario. Secondly, delivery of the learning materials to learners is handled by instruction module of control station (e.g., the questions asked by the instructor and the answers given by the learners). Finally, the presentation module displays the summarized information from the notification module at the control station, such as the brief statistical results, pie chart and other visual presentation for the instructor to aware all learners' situations in a real time manner.

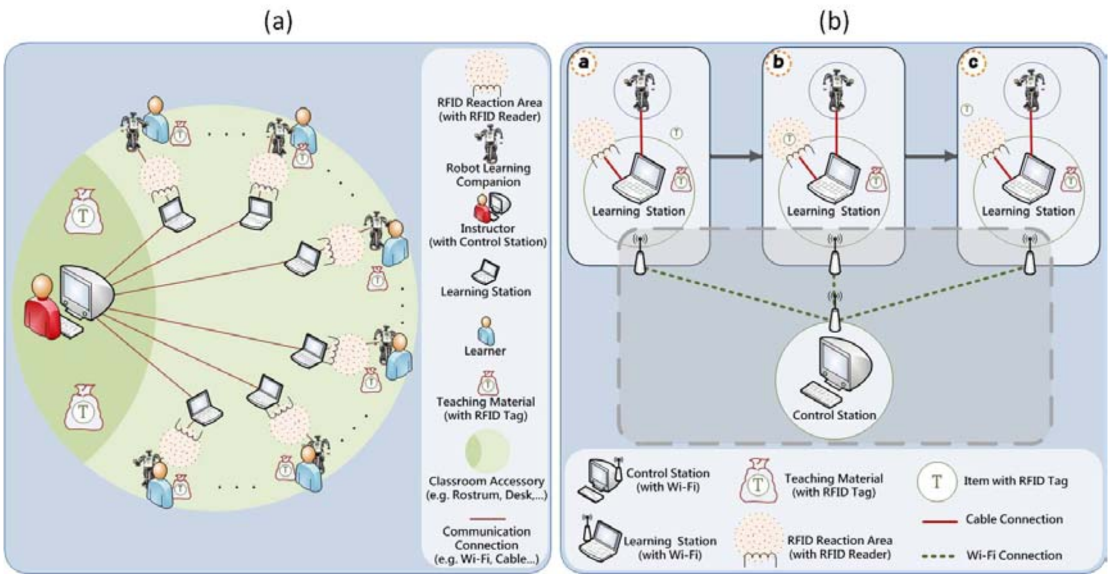

Figure 2: (a) Sketch map of the JCLS; (b) A typical instruction mode connections of the JCLS

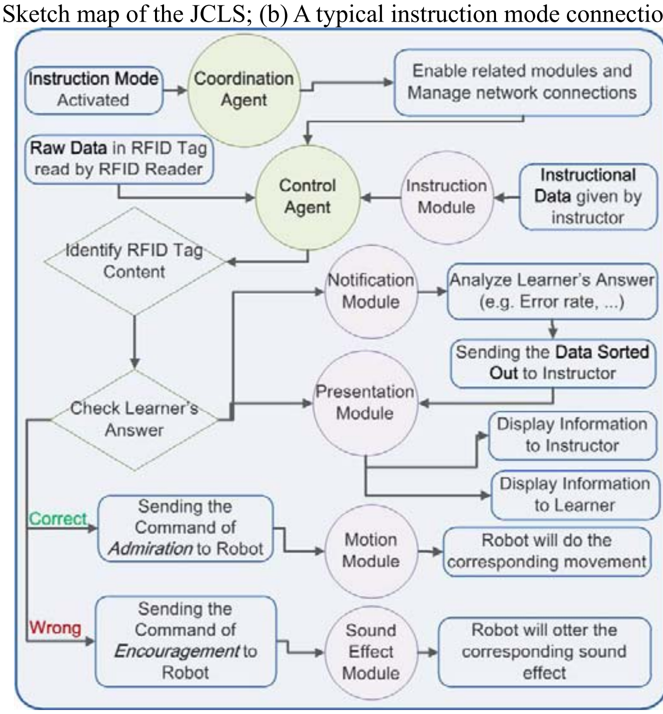

Figure 3: The flow chart for instruction mode of the JCLS

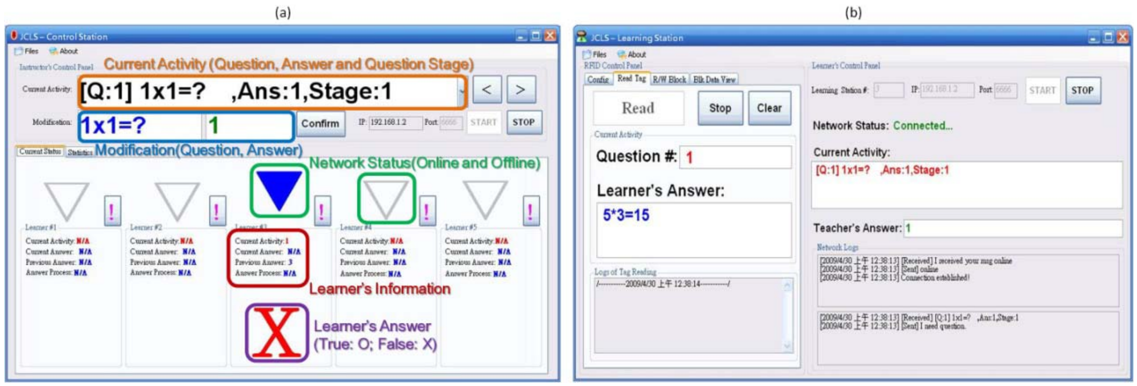

Figure 4: (a) Control station (JCLS_CS); (b) Learning station (JCLS_LS)

METHODOLOGY

Participants

To evaluate the developed system, this research conducted two experiments, namely pilot experiment (Chen, Hung, & Wei, 2010) and formal experiment. The pilot experiment helped improve formal experiment more completely and the all participants of it were different from the formal experiment. The formal experiment, including an experimental group and a control group, was conducted with 47 elementary school students in grade two. As shown in Figure 5(a), the experimental group, composed of 24 students including 9 boys and 15 girls, was arranged to learn with the JCLS. The control group as shown in Figure 5(b), composed of 23 students including 10 boys and 13 girls, was arranged to learn with traditional learning method by using the blackboard.

Figure 5: (a) Experimental group learn with the JCLS (b) Control group learn with traditional learning method

In order to maintain better quality for observation during the learning process, the maximum number of participants in the experimental group is limited to six students in each round. The experimental group therefore divided into four rounds. The participants of experimental group and control group were from two different classes. The observation method, questionnaires, and interviews were adopted for data collection in this research.

Experimental Procedures

The experimental procedures comprise the experimental group and the control group respectively. For the experimental group procedure, there were seven steps as shown in Figure 6(a).

Step 1: Set up the environment and introduce the goal of this formal experiment. The instructor gave physical learning materials with 11 RFID tags containing ten numbers (0 to 9) and two command symbols (enter and clear). Control station had pre-prepared item-bank database about learning multiplication and every learner was provided with a learning station.

Step 2: Instruction on how to use the JCLS. The instructor gave an introduction in five minutes to the learners about how to use the JCLS. Learners use a hammer shape RFID reader to touch a desired RFID tag (representing the number among 0-9) while they were trying to answer a multiplication question/exercise.

Step 3: Instruction on principles of multiplication. The instructor then provided the instructions about the topic of multiplication. All available instructional strategies could be used for instruction. For example, Learning by doing by giving enough time for learners to practice was the predominant strategy as it is found to be more effective for learning and knowledge construction (Appelman, 2004; Bruckman, 1998; Cronjé, 2006; Dewey, 1938; Kolb & Kolb, 2005; Piaget, 1968).

Step 4: Exercise practices with the JCLS. The instructor gave several questions related to the topics which were taught in the previous step. Learners used RFID tags to input their answers or calculation process, if they cannot get the correct answers, they are free to try for several times, and the RLC will spontaneously react to learners with proper actions or sounds based on the inputs (Figure 7). In such kind of design, every learner in the JCLS's learning environment has a "fair opportunity" to be engaged in the hands-on practice. The JCLS actively but silently logged all learning activities of each learner in the background at the same time.

Step 5: The instructor choose the best question for the next exercise based on the feedback of the whole learners of the experimental group. The instructor was able to timely receive the summarized information about learners such as the accuracy of answering questions. Furthermore, the instructor can use more detail information in the learning activity logs of an individual learner for analyzing learning obstacles and provide customized assistance to the specific learner. The steps of Step 4 and Step 5 usually repeated a couple of times until most learners had achieved the designated learning goal.

Step 6: Fill the questionnaire. Once the instructor finished the instruction process and verified that the learners had achieved the learning outcomes, the instructor ended the learning activity. All learners were then asked to fill the questionnaire designed for evaluating the extent of the three main constructs of this research, including experiential learning, constructivist learning, and joyful learning.

Step 7: One-to-one interview. The interview focused on the understanding of learners' perceptions about using the JCLS. Each interview was approximately 10 minutes in duration. The interview questions were about how the learner's perceived differently between learners in the experimental group and in the control group.

For the control group procedure, there were five steps as shown in Figure 6(b). Step 1 and step 2 were identical as the experimental group except for setting up the environment.

Step 3: Exercise practices with traditional blackboard. The instructor gave questions related to the topics just taught in the previous step to only a few students and asked them to answer by using the blackboard. Due to the space limitation of the blackboard, it is not possible for every learner to have a fair opportunity to do hands-on practice.

Step 4: Instructor gave a question for the next exercise based on the feedback of those few students who had practiced on the blackboard. As the instructor cannot get the whole picture of all students' learning status, the adjustment of instructional strategies can only rely on the instructor's subjective experience. The processes of Step 3 and 4 could also repeat a couple of times which was decided by the instructor.

Step 5: Fill the questionnaire. While instructor completed the instruction, the learning activity was ended as well. All learners were asked to fill the questionnaire.

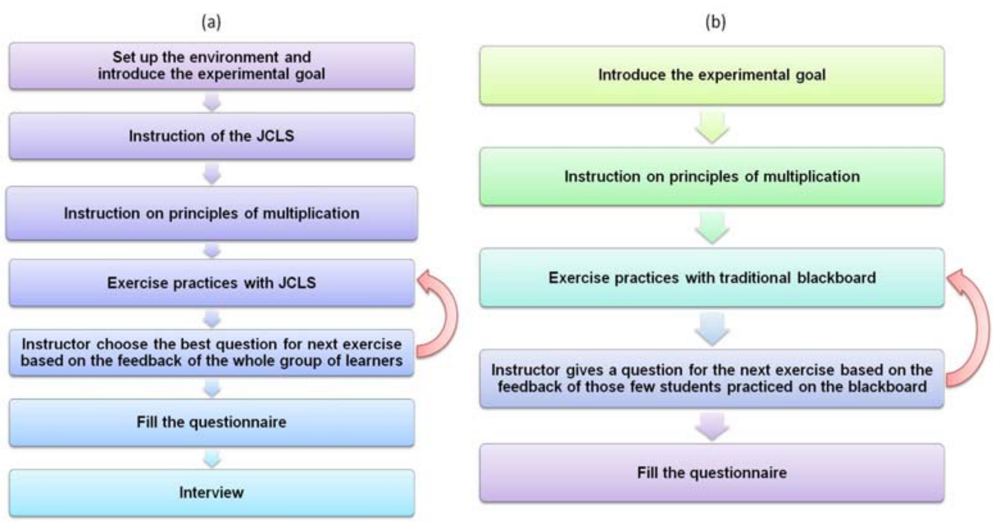

Figure 6: Experimental procedures: (a) Experimental group (b) Control group

Figure 7: Learners can practice several times with the JCLS

Data collection

The collected data of the formal experiment includes four different parts, namely pre-test, questionnaire, observation and interview. Firstly, the pre-test were used to test if the participants in the experimental group and the control group have the same level of mathematic performance before the formal experiment. There were three basic multiplication questions used for the pre-test. Secondly, a questionnaire was given to all participants for acquiring their feedback and perceptions. Thirdly, observation data were recorded during the whole learning activity in the formal experiment. Finally, interview was used to obtain the deeper understanding of the learners in experimental group. All collected data were analyzed for findings using triangulation validation method (Armstrong, Gosling, Weinman, & Marteau, 1997).

The questionnaire includes three different parts which is corresponding to the three constructs of experiential learning, constructivist learning and joyful learning respectively. Each construct has four items in the questionnaire and adopts ten-point Likert scale. The reasons why using ten-point Likert scale are as follows: (a) the ten-point Likert scale for children is easier to understand compared to other kinds (Van Laerhoven, van der Zaag-Loonen, & Derkx, 2004); (b) the option like neither agree nor disagree is not available because the neutral option for assessing the perception of each item is not suitable, so the forced choice method (Dunnette, McCartney, Carlson, & Kirchner, 1962) was adopted in this research; and (c) the markings in Taiwan usually use centesimal grading and the children learners also expressed that using scores from 1 to 10 are more understandable in the pilot experiment (Chen, Hung, & Wei, 2010).

At the end of the formal experiment, forty-three valid questionnaires were collected including twenty-two from the experimental group and twenty-one from the control group after eliminating three invalid samples (i.e., outliers or missing data). The sampling accuracy assessed by the Kaiser-Meyer-Olkin (KMO) is .769 which is better than the recommended value of .60 (Kaiser, 1974). After that, the factor analysis was used to examine the convergent validity between items in the same construct and the discriminant validity between items among different constructs. The principal component method of factor analysis was used with Varimax (orthogonal) rotation. The JL2 item was removed because items that do not load together may be removed from the questionnaire (Churchill, 1979). The EL3 item was also removed because it is recommended that no item cross-loadings should be above .40 (Hair, Anderson, Tatham, & Black, 1998). The factor loadings of the CL1 item is lower than the minimum factor loading .60 on its hypothesized constructs proposed (Nually, 1978), so CL1 was also removed. The result of factor analysis after removing these three items is listed in Table 3.

Table 3: Rotated component matrix after removing three items

	Component		
	Factor 1	**Factor 2**	**Factor 3**
JL 1	.857		
JL 3	.877		
JL 4	.867		
EL 1		.869	
EL 2		.767	
EL 4		.754	
CL 2			.867
CL 3			.754
CL 4			.634

According to Table 3, three components were labeled as joyful learning (JL), experiential learning (EL), and constructivist learning (CL) respectively. Internal consistency was evaluated using Cronbach's alpha. The Cronbach's alpha reliability coefficients were all higher than the minimum cutoff value of .70 (Table 4) and hence good for the follow-up analysis (Hair, et al., 1998; Nunnally & Bernstein, 1994).

Table 4: Reliability analysis results

Construct	**Cronbach's alpha**
Experiential Learning	.809
Constructivist Learning	.765
Joyful Learning	.926

The observation form designed in this research comprises several observable indicators, namely perception about instruction, the problem solving process, the facial expression, the gesture, and the learning atmosphere. The observable indicators are designed according to the three nexus concepts of the experiential learning, the constructivist learning and the joyful learning. The first part is to observe whether the learners are actively engaged in answering the questions given by instructor. The second part is to observe whether the learners will do several tries to figure out the correct answer while the robot learning companion (RLC) tells them the answer was wrong. The third part is to observe whether the learners would feel joyful perceptions while the RLC tells them with cheerful messages like "You are right" or "Good job". The last part is to observe whether the overall learning atmosphere was hedonic.

The operations of the interview focused on digging more detail information about how the learners used the JCLS to perform learning activities. Six interviewees participated in this one-to-one interview. Each interviewee spent approximately 10 minutes on completing the whole interview process. The open-structure questions of this interview were about the different perceptions of the learners between using the JCLS and the traditional learning method in learning mathematics.

RESULTS

The first test was performed to confirm whether the experimental group and the control group learners were having the same level of multiplication knowledge by analyzing the data collected from the pre-test. The results show that both experimental group and control group learners got the same mean score for the pre-test, which implies their initial points were the same.

Secondly, the data collected from the questionnaire was evaluated by independent t-test analysis and the result is shown in Table 5. A significant difference ($p < .000$) between the experimental group and control group was also found for the experimental learning construct. For the constructivist learning construct, there was a significant difference ($p < .000$) between the experimental group and control group. For the joyful learning construct, there was also a significant difference between these two groups despite the p-value is equal to .043 which is close to the significant boundary.

Table 5: Independent t-test of differences in experimental and control groups

Construct		t	df	Sig. (2-tailed)	Mean Difference
Constructivist Learning	*CG* *EG*	-5.988 ***	32.964	.000	-2.46825
Experiential Learning	*CG* *EG*	-6.958 ***	21.851	.000	-3.26768
Joyful Learning	*CG* *EG*	-2.156 *	20.567	.043	-.864

Note: * p<.05; ** p<.01; *** p<.001;
CG - Control Group; *EG* - Experimental Group

Thirdly, the analyzed results from the observation are shown in Table 6. Both observable indicators of learners do the hands-on practice actively, and several tries to figure out the correct answer show very high percentage (94.45%). Furthermore, 90.91% of learners would feel very happy when got praise from the RLC, and the overall learning atmosphere is very hedonic.

Table 6: The observation result of the experimental group

Observable Indicator	N	Percentage
Learners do the hands-on practice actively	21	95.45%
Learners do several tries to figure out the correct answer	21	95.45%
Learners feel happy (having joyful perceptions) e.g., smiles	20	90.91%
Overall learning atmosphere is hedonic	22	100%

Note: The total valid number of all learners in experimental group is 22.

Finally, the results from the interviews can be summarized as follows: (a) most learners agreed that using blackboard for exercises were to limited, however using the JCLS with RLC really enhanced their learning motivations; (b) Many learners also acknowledged that learning with RLC was much interesting than learning in a traditional classroom; and (c) some learners expressed that the opportunity of making several tries to figure out the correct answer was very useful for them to figure out why the mistakes they had made.

DISCUSSIONS

With the results stated above, some discussions and implications can be further elaborated by using data triangulation. Firstly, for the experiential learning, the "learning by doing" strategy was adopted in experimental learning. Learners learned multiplication of mathematics through hands-on practices including using quantities of tangible objects in reality or drawing numbers of intangible objects on the blank paper for calculation. The questionnaire results found that the learners in the experimental group had deeper impression about the teaching mathematics content through hands-on exercises by using the JCLS. However, in control group, there are only about a few learners had the chance to use blackboard for hands-on practices, and some of these learners may be uncomfortable as they were forced to practice in front of all other learners. In the interview, one learner said that he did not like being forced to solve problems with blackboard, and if the RLC could tell him right or wrong, he will be glad to practice these exercise on his own. Therefore, the JCLS did allow every learner to have the "fair opportunity" of doing each hands-on practice which in turn deepened their impressions about the learning contents.

Secondly, for the constructivist learning, learners can have several chances to revise their answer for a question by the feedback of peers and instructions/assistance of the instructor. Through this kind of repeating process, learners can unceasingly refine their concepts of multiplication calculation and finally obtain the correct knowledge of multiplication calculation. There were two major differences between the experimental group and the control group. One was the learning feedback responsiveness and the other one was hands-on exercises opportunity. In traditional classroom teaching environments, instructors can only base on their subjective teaching experiences to adjust their instructional strategies for guiding learners to think. If instructors want to adjust their instructional strategies based on the feedback of every learner during the class, it would be very time-consuming and less efficient. However, instructors can easily see every learner's learning status in the JCLS and immediately adjust their instructional strategies based on the timely feedback during the class. On the other hand, all learners can try to do exercises at the same time for several times with the support of the JCLS. This kind of re-try process is very useful for constructing one's own mathematics knowledge.

Thirdly, for the joyful learning, it was found that joyful learning had positive influences on learning motivations from the observation and interviews. Many learners were observed that they showed a high degree of interest in interacting with the robot learning companion. For example, there were two learners waved their hands to the RLCs (Figure 8(a)) which implies learners truly thought RLC as their learning companion (i.e., partner). And many learners also have dense interests about the RLC (Figure 8(b)). Some learners expressed during the interview that the classes of the experiment group and control group were more interesting than their ordinary mathematics classes, and the classes with the JCLS were the most interesting. When learners have higher interests and joyful perceptions during the learning process, their learning motivations will be higher and their learning outcomes will be better.

Figure 8: Learner (a) Wave hands to RLC (b) Highly interested in interacting with RLC

Finally, in the pilot experiment, two parents expressed their concern about using RFID tags for simple numeric answer input might take too much time than directly writing down on the paper in the class. In other words, the two parents were worried about the complexity of operating the ICT devices. Two independent constructs of TAM (Davis, 1989), namely perceived usefulness (PU) and perceived ease of use (PEOU) were adopted. The main purpose focused on understanding how the learners felt the JCLS on usefulness and ease of use. So in the formal experiment, the data of the perceived usefulness and the perceived ease of use based on the TAM questionnaire were collected to confirm the acceptance of the JCLS for children's mathematics learning. The results (Table 7) show that the scores of both perceived usefulness and perceived ease of use were very high which very close to the maximum value of the scale. According to the result of analysis, the concern issue from two parents of participants in the pilot experiment can be regarded which was not truly happened.

Table 7: Result on usefulness and ease of use

	N	Mean	Std. Deviation
Perceived Usefulness (PU)	22	9.58	0.51
Perceived Ease of Use (PEOU)	22	9.35	0.91

CONCLUSIONS

The aim of this research is to design and evaluate a JCLS for supporting children's learning by using RLC and RFID technologies. The results show that the JCLS can help children learners to have better learning experiences in terms of experiential learning, constructivist learning and joyful learning. Many learners responded that JCLS could increase their learning motivations and help them concentrate on the instruction and learning activity. Results also found that children learners were well-perceived the usefulness and ease of use of the JCLS. The main contribution of this research is to show the feasibility and potential of applying educational robots and RFID technologies to help children learners to do mathematical learning.

There are two limitations in this research. Firstly, this research did not investigate the learning performance because this research was focused on the design and implementation of the JCLS to support children's learning. Future research should consider conducting a long-term experiment to investigate the effects of learning performance and the differences across various grade levels. The second limitation is the learning contents designed in this research was not suitable for adaptive learning. How to design adaptive learning contents driven by robot learning companion would be a very promising future research topic.

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REFERENCES

Appelman, R. (2004). Designing experiential modes: A key focus for immersive learning environments. *TechTrends, 49*(3), 64-74.

Armstrong, D., Gosling, A., Weinman, J., & Marteau, T. (1997). The Place of Inter-Rater Reliability in Qualitative Research: An Empirical Study. *Sociology, 31*(3), 597-606.

Barab, S., Thomas, M., Dodge, T., Carteaux, R., & Tuzun, H. (2005). Making learning fun: Quest Atlantis, a game without guns. *Educational Technology Research and Development, 53*(1), 86-107.

Barker, B. S., & Ansorge, J. (2007). Robotics as Means to Increase Achievement Scores in an Informal Learning Environment. *Journal of Research on Technology in Education, 39*(3), 229-243.

Bruckman, A. (1998). Community Support for Constructionist Learning. *Computer Supported Cooperative Work: The Journal of Collaborative Computing, 7*(1-2), 47-86.

Chen, L., Chen, T. L., & Liu, H. K. J. (2010). Perception of Young Adults on Online Games: Implications for Higher Education. *The Turkish Online Journal of Educational Technology, 9*(3), 76-84.

Chen, N. S., Hung, I. C., Lee, L., & Wei, C. W. (2010). *Exploring the Impact of Children's Mathematics Learning in the Ubiquitous Learning System with Robot Learning Companion*. Paper presented at Asia-Pacific Conference on Technology Enhanced Learning (APTEL 2010), Osaka, Japan.

Chen, N. S., Hung, I. C., & Wei, C. W. (2010). Developing Ubiquitous Learning System with Robots for Children's Learning. In G. Biswas, D. Carr, Y. S. Chee & W. Y. Hwang (Eds.), *Proceedings of the 3rd IEEE International Conference on Digital Game and Intelligent Toy Enhanced Learning (DIGITEL 2010)* (pp. 61-68). Kaohsiung City, Taiwan: IEEE Computer Society Press.

Chen, N. S., Kinshuk, Wei, C. W., & Yang, S. J. H. (2008). Designing a self-contained group area network for ubiquitous learning. *Educational Technology & Society, 11*(2), 16-26.

Chen, N. S., Lin, K. M., & Kinshuk (2008). Analysing users' satisfaction with e-learning using a negative critical incidents approach. *Innovations in Education and Teaching International, 45*(2), 115 – 126.

Chen, N. S., & Tsai, C. C. (2009). Knowledge infrastructure of the future. *Educational Technology & Society, 12*(1), 1-4.

Cheng, H. N. H., Wu, W. M. C., Liao, C. C. Y., & Chan, T. W. (2009). Equal opportunity tactic: Redesigning and applying competition games in classrooms. *Computers & Education, 53*(3), 866-876.

Chung, P. Y., Chang, C. J., Liang, Y. D., Shih, B. Y., Lin, M. Z., Chen, T. H., et al. (2010). Design, Development and Learning Assessment by Applying NXT Robotics Multi-Media Learning Materials: A Preliminary Study to Explore Students'Learning Motivation *World Academy of Science, Engineering and Technology, 65*, 1102-1106.

Churchill, G. A. (1979). A paradigm for developing better measures of marketing constructs. *Journal of Marketing Research, 16*(1), 64-73.

Cronjé, J. (2006). Paradigms Regained: Toward Integrating Objectivism and Constructivism in Instructional Design and the Learning Sciences. *Educational Technology Research and Development, 54*(4), 387-416.

Davis, F. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319-340.

Dewey, J. (1938). *Experience and education.* New York, NY: Simon and Schuster.

Dunnette, M., McCartney, J., Carlson, H., & Kirchner, W. (1962). A study of faking behavior on a forced-choice self-description checklist. *Personnel Psychology, 15*(2), 13-24.

Fasola, J., & Mataric, M. J. (2010). *Robot Motivator: Increasing User Enjoyment and Performance on a*

Physical/Cognitive Task. Paper presented at Proceedings of the the Ninth IEEE International Conference on Development and Learning (ICDL 2010), Ann Arbor, MI: IEEE Computer Society Press.
Fisher, B. (1998). *Joyful learning in kindergarten*. Portsmouth, NH: Heinemann.
Flavell, J. H. (1963). *The developmental psychology of Jean Piaget.* New York, NY: Van Nostrand Reinhold.
Francis, A., & Mishra, P. (2009). Is AIBO Real? Understanding Children's Beliefs About and Behavioral Interactions with Anthropomorphic Toys. *Journal of Interactive Learning Research, 20*(4), 405-422.
Hair, J. F., Anderson, R. E., Tatham, R. L., & Black, W. C. (1998). Multivariate Data Analysis (5th ed.).
Heywood, P. (2005). Learning joyfully: An emotional and transformative experience. *Melbourne Studies in Education, 46*(1), 33-44.
Huang, Y. M., Kuo, Y. H., Lin, Y. T., & Cheng, S. C. (2008). Toward interactive mobile synchronous learning environment with context-awareness service. *Computers & Education, 51*(3), 1205-1226.
Jarvinen, E. M. (1998). The Lego/Logo Learning Environment in Technology Education: An Experiment in a Finnish Context. *Journal of Technology Education, 9*(2), 47-59.
Jermann, P., Soller, A., & Mühlenbrock, M. (2001). *From mirroring to guiding: A review of the state of art technology for supporting collaborative learning*. Paper presented at the European Conference on Computer-Supported Collaborative Learning (Euro-CSCL 2001), Maastricht, Netherlands.
Johnson, J. (2003). Children, robotics, and education. *Artificial Life and Robotics, 7*(1), 16-21.
Jones, V., Jo, J. H., & Han, J. (2006). The Future of Robot-Assisted Learning in the Home. *International Journal of Pedagogies and Learning, 2*(1), 63-75.
Kaiser, H. (1974). An index of factorial simplicity. *Psychometrika, 39*(1), 31-36.
Kebritchi, M., & Hirumi, A. (2008). Examining the pedagogical foundations of modern educational computer games. *Computers & Education, 51*(4), 1729-1743.
Kirikkaya, E. B., İşeri, Ş., & Vurkaya, G. (2010). A Board Game about Space and Solar System for Primary School Students. *The Turkish Online Journal of Educational Technology, 9*(2), 1-13.
Klassner, F., & Anderson, S. D. (2003). LEGO MindStorms: not just for K-12 anymore. *Robotics & Automation Magazine, IEEE, 10*(2), 12-18.
Kolb, A. Y., & Kolb, D. A. (2005). Learning styles and learning spaces: Enhancing experiential learning in higher education. *Academy of Management Learning and Education, 4*(2), 193-212.
Kolb, D. A. (1984). *Experiential Learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice Hall.
Lindh, J., & Holgersson, T. (2007). Does lego training stimulate pupils' ability to solve logical problems? *Computers & Education, 49*(4), 1097-1111.
Mitnik, R., Nussbaum, M., & Soto, A. (2008). An autonomous educational mobile robot mediator. *Auton. Robots, 25*(4), 367-382.
Mitnik, R., Recabarren, M., Nussbaum, M., & Soto, A. (2009). Collaborative robotic instruction: A graph teaching experience. *Computers & Education, 53*(2), 330-342.
Morais, R., Fernandes, M. A., Matos, S. G., Serôdio, C., Ferreira, P. J. S. G., & Reis, M. J. C. S. (2008). A ZigBee multi-powered wireless acquisition device for remote sensing applications in precision viticulture. *Computers and Electronics in Agriculture, 62*(2), 94-106.
Motiwalla, L. F. (2007). Mobile learning: A framework and evaluation. *Computers & Education, 49*(3), 581-596
Nually, J. C. (1978) *Psychometric Theory*. New York, NY: McGraw-Hill.
Nunnally, J. C., & Bernstein, I. H. (1994). *Psychometric Theory*. New York, NY: McCraw-Hill.
Piaget, J. (1968). *Six Psychological Studies*. New York, NY: Vintage.
Piaget, J. (1970). *Science and education and the psychology of the child.* New York, NY: Orion Press.
Ruiz-del-Solar, J., & Aviles, R. (2004). Robotics courses for children as a motivation tool: the Chilean experience. *Education, 47*(4), 474-480.
Schiaffino, S., Garcia, P., & Amandi, A. (2008). eTeacher: Providing personalized assistance to e-learning students. *Computers & Education, 51*(4), 1744-1754.
Tsai, C. C., Chen, N. S., & Chen, G. D. (2010). The current status and future of e-learning in Taiwan. *Innovations in Education and Teaching International, 47*(1), 5-7.
Van Laerhoven, H., van der Zaag-Loonen, H. J., & Derkx, B. H. F. (2004). A comparison of Likert scale and visual analogue scales as response options in children's questionnaires. *Acta paediatrica, 93*(6), 830-835.
Washburne, J. N. (1936). The definition of learning. *Journal of Educational Psychology, 27*(8), 603-611.
You, Z. J., Shen, C. Y., Chang, C. W., Liu, B. J., & Chen, G. D. (2006). A Robot as a Teaching Assistant in an English Class. In Kinshuk, R. Koper, P. Kommers, P. Kirschner, D. G. Sampson & W. Didderen (Eds.), *Proceedings of the 6th IEEE International Conference on Advanced Learning Technologies (ICALT 2006)* (pp. 87-91). Kerkrade, Netherlands: IEEE Computer Society Press.
Zhang, Y., Kinshuk, Jormannainen, I., & Sutinen, E. (2008). An Implementation of the Agency Architecture in Educational Robotics. In P. Díaz, Kinshuk, I. Aedo & E. Mora (Eds.), *Proceedings of the 8th IEEE International Conference on Advanced Learning Technologies (ICALT 2008)* (pp. 194-198). Cantabria, Spain: IEEE Computer Society Press.