Developing Ubiquitous Learning System with Robots for Children's Learning

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***Abstract*—An advanced learning system architecture with several flexible, mobile and joyful ICT features for the ubiquitous learning is proposed in this research based on experiential learning theory, constructivism learning theory and joyful learning feature. The architecture consists of five hardware key elements and supporting software to form a brand-new ubiquitous learning system. We call the designed system as Ubiquitous Open-structured Neo-tech Edutainment (u-ONE System) which comprises learning robot, sensing input device, mobile computing device, mobile output device, wireless local network and u-ONE Software. Three different application modes including instruction, collaborative learning and self-learning are supported by u-ONE Software for realizing the broad sense of ubiquitous learning. The aim of this research is to design and develop a prototype of u-ONE System consists of hardware and software components for supporting children's learning by using robot and RFID. The experiment results show most learners could arouse good learning motivations and more concentration on learning activities by using u-ONE System.**

Keywords-Ubiquitous learning; robot; RFID; joyful learning; u-ONE

I. INTRODUCTION

The universal definition of learning is a process of acquiring knowledge, technique, attitude and value through instruction and experience [20]. Human intelligence development is affected by the inborn conditions and acquired contexts since childhood. The development process contains several steps; the time required for reaching each step is different for each individual learner; because each previous step is the foundation of posterior step, the sequence is successive [7, 17]. Therefore, developing a suitable learning environment with proper learning sequence is very essential for effective learning especially for children who are just in the early development period.

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: concrete experience, reflective observation, abstract conceptualization and active experimentation [1, 13]. It's a repeated cycle for the continuous experience and exploration [12]. Based on ELT, younger learners would get a stronger impression about things if they could touch and practice real objects; this is the reason why robot and RFID are adopted in the developed system. Meanwhile, learners can concentrate in acquiring knowledge, skills and values through repeated self-reflection [6].

Once younger learners got stronger impressions from their experiences and comprehensions, the knowledge will be constructed by themselves; knowledge cannot be directly supplied by instructors or others, this is the core concept of constructivism learning theory [2, 5, 18]. Instructor is to play the role of an organizer, facilitator and resource provider to help children's learning. Besides, the importance of joyful learning for children is being emphasized in recent years. A joyful perception would result positive influences on learning motivations. A number of modern educational games were hence developed to carry out pedagogical theories and strategies [11]. Interactive learning robot is used in the learning process and expected to bring some sort of joyful perceptions to learners in this research.

This research includes two main dimensions, learning dimension and instruction dimension. In the learning dimension, the problem cognition and problem solving abilities are important to learners and could be cultivated through the learning processes. The issue of how to cultivate these two abilities is very critical in childhood age when a learner began to learn and receive instruction. Therefore, the goal of learning dimension is to train and cultivate learners' problem cognition and problem solving abilities [14].

In instruction dimension, if instructors simply use oral speaking to explain learning materials, sometime learners still cannot comprehend the meaning, they can use physical objects or tangible tools to help. For example, instructors might utilize physical learning materials to enhance learners' realization about learning contents. However, instructors still cannot exactly have the real-time learning statuses, evaluations, and feedback about learners in conventional learning environments without any

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information and communication technology (ICT) support. The ICT advancements have made e-Learning [4, 19] and mobile learning [8, 16] more and more popular in our daily life. When adopting e-Learning environment especially for children, such as online lectures and cyber classroom, are inevitable to bring learners more burdens on getting experiences of using ICT. No matter what kind of online learning environment is being adopted, the learners will be forced to use ICT to engage in learning activities even if they only have less or even no ICT using experience and know-how. In the mean time, instructors also need to pay more attention and energy on conducting instructions online than before. Hence, it is very important and necessary to apply new learning technologies with new learning methods for better facilitating children learning, but minimize the extra burdens caused by the barrier of using ICT.

The objective of this research is to design and develop a prototype of Ubiquitous Open-structured Neo-tech Edutainment (u-ONE System) which consists of hardware and software components for supporting children's learning. The developed system is based on experiential learning theory, constructivism learning theory and joyful learning feature by using robot and RFID. The "Ubiquitous" of u-ONE System indicates that it is a kind of generalized ubiquitous leaning; the "Open-structured" means that the combinations of hardware elements and software implementation have flexibilities to modify; the "Neo-tech" states new ICT would be applied such as robot; the last word "Edutainment" is as the literal meaning which includes both educational and entertainment features.

The aim is to support different learning scenarios such as conventional physical classroom, outdoor space and home through three designed application modes including instruction, collaborative learning and self-learning. The learning activities in u-ONE System with its software (u-ONE Software) designed in this research could (a) provide the ease of use and joyful learning features; (b) play a mediator role between instructor and learners or as self-learning companions; (c) provide additional information to physical learning materials; and (d) form a new learning model with using ICT for education.

II. ROBOT-RELATED APPLICATIONS IN EDUCATIONAL FIELD

In the nearly future, school-age children may have learning robot accompany them for learning and assist them to comprehend the learning materials [10]. Before discussing robot applications in educational field, the kinds and utilities of robot is the first thing needed to understand. Generally, there are three kinds of robots, namely (a) interactive recreation robot toy, (b) assemble education & recreation robot, and (c) platform-dependent development robot kit. First, interactive recreation robot toy is a general classification that people think it just play a role of toy, for example Wowwee's Spain series or SONY's AIBO robot dog. The original idea of this robot is designed for entertainment, so it does not have too much complex functions or reconfigurable capabilities. But, it is possible to use in conventional physical classroom for assisting teaching through some modifications and designing suitable learning activities [21]. Second is the assemble education & recreation robot such as the widely known LEGO MINDSTORMS series. Most schools use this kind of robot for training and stimulating logical thinking abilities for pupils through assembling a robot with LEGO bricks and programming it in the visual programming system (VPS), like LEGO's ROBOLAB software or some other third-party products [9, 14]. Besides, there are some researches focusing on providing an agency system to assist instructor in monitoring learners' learning statuses with robot [22]. The third kind is platform-dependent development robot kit which is designed for a specific research or purpose and can satisfy most requirements. Higher level hardware, complex functions, and flexible configuration can be helpful for applying to advanced applications.

III. ARCHITECTURE OF U-ONE SYSTEM

A. Key hardware elements

Learning robot, sensing input device, mobile computing device, mobile output device and wireless local network construct the whole u-ONE System. These five elements are essentially required for designing different learning scenarios in u-ONE System. The practical use of each kind of devices is flexible for adoption depending on designed learning activities and available products on the market during the timeframe. The products and main functions of these five elements are listed in Table I.

Learning robots in this research as digital learning companion (DLC) are used to interact with primary school children. There are two main purposes of DLC. One is to help instructors to provide real-time information and feedback for learners and collect learning status from learners. The other is to create a tangible learning companion for learners and make them have joyful perception. The DLC can attract learners' attentions to arouse their learning motivations and guide them to focus on the learning activities. In this research, the LEGO MINDSTORMS NXT is adopted to be the learning robot and mobile output device. The RFID is used for the sensing input device. The mobility of computing device is crucially required because it helps learners easily reconstruct the identical learning environment by themselves. At present, the laptop is more obtainable as a mobile computing device. The prototype of the developed u-ONE System presently adopted Wi-Fi to construct wireless local network for information exchange due to the consideration of popularity and compatibility. Others more autonomic wireless local network technologies such as the ZigBee [15] or GroupNet [3] are possible for replacing Wi-Fi when they become more mature and widespread.

TABLE I. FIVE MAIN ELEMENTS IN THE U-ONE SYSTEM

Element	Product example	Function
Learning robot	LEGO MINDSTORMS, Wowwee Robosapien, and Aldebaran Robotics Nao	Interaction
Sensing input device	Barcode, RFID, QR Code, Electronic Pen, Magnetic Card, and Laser Projector Keyboard	Input
Mobile computing device	Laptop, OLPC, Netbook, PDA, Smartphone, and iPod	Process and storage
Mobile output device	Portable Projector, Touch Screen, Electronic Paper, and Eye Screen	Output
Wireless local network	Bluetooth, Low Power Wi-Fi, ZigBee, and GroupNet	Data communication

B. Application modes

The first mode supported by u-ONE Software is called instruction mode (Fig. 1(a)). When learners learn with u-ONE System and have support of u-ONE Software during a class, they can take the advantages such as equal opportunities for participating learning activities. Every learner will have a DLC for guiding them to focus on learning activities facilitated by instructor's instruction. For example, every learner could have the same opportunity to participate in learning activity provided by instructor with DLC's support during a class. Every learner in u-ONE System would be more engaged and have more participation perception than traditional sit-and-listen leaning environment. Learners also do not worry about the complex ICT operations while having the u-ONE Software support. Instructor can use instruction mode to quickly deploy instructional materials or learning contents to learners in the class. Meanwhile, learning status of every learner will be automatically logged and sorted during the learning activity. Instructor could easily access the detailed information about learners' learning statuses through the wireless local network. The u-ONE Software will show a summary but important information about learners' learning statuses to instructor by mobile output device as well. Instructor could realize the summarization about every learner's learning status and give prompt assistance to learners. Furthermore, u-ONE Software has complete and detailed logs about every learner's learning status, such that making a deep analysis about learning pattern of each individual learner become possible. Instructor can then better understand the learning obstacles of each learner. Based on this information, instructor can provide adaptive instruction to each individual learner such that guiding learners in accordance with their aptitude can be realized.

The second mode is the collaborative learning mode (Fig. 1(b)). The u-ONE Software provides a grouping mechanism to support collaborative learning. Learners can be grouped into several teams for carrying out collaborative learning activities. Most steps among the holistic process would be automatically conducted by u-ONE Software. Simultaneously, the collaborative learning activity in u-ONE System will not be restricted to the fixed location such as physical classroom at school. The features of flexibility, mobility, and joyful feature could be included for collaborative learning activity in u-ONE System and expecting to gain more positive effects for holistic learning process. As long as the learning activity is well designed, instructor would not directly involve in learners' collaborative learning process, but play a role of facilitator. Instructor just stands by for the unforeseen situation and gives proper assistance if necessary. Besides, u-ONE Software also provides instructor with updated information about each team's progress for assuring whether the goal of learning activity has been achieved.

The third mode supported by u-ONE Software is the self-learning mode (Fig. 1(c)). This mode is supposed to be a useful way for learners to preview or review learning contents. The u-ONE Software in this mode is simpler than the other two modes. Because less information exchange is needed to be handled, u-ONE Software just focuses on providing learning contents. The u-ONE Software will provide learners with suitable learning contents depending on the built-in learning materials database and the feedback from the learner. This is the concept of the adaptive learning materials which can timely adjust the learning contents to make the learning process more effective for a specific learner. On the other hand, learners in this mode will have the opportunity to learn something on their own demands. Besides, the information from learning robot or mobile output device could help learners to take appropriate actions during a learning process such as checkpointing, retrying and reflecting. Definitely, all learning statuses will be well recorded as well.

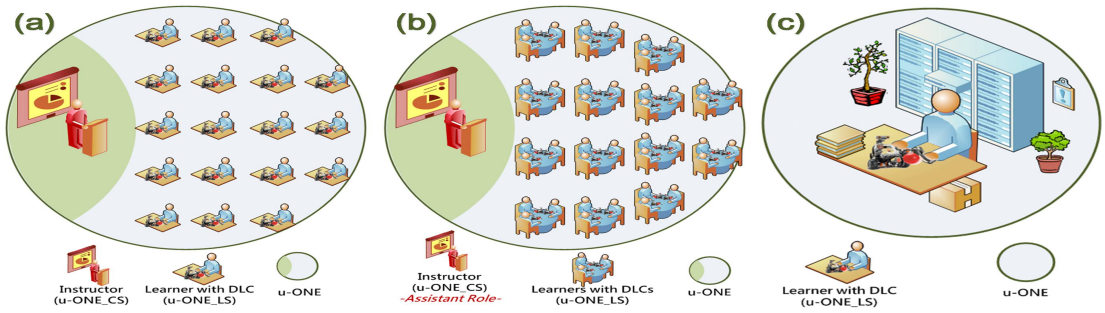

Figure 1. Application modes of u-ONE Software: (a) Instruction; (b) Collaborative learning; (c) Self-learning

IV. Design and Implementation of u-ONE System

As the sketch map of u-ONE System (Fig. 2(a)) shown, every learner will have a learning station including learning robot, sensing input device, mobile computing device, mobile output device and wireless local network. The learning station is consisting of the LEGO MINDSTORMS NXT, laptop, RFID reader and tags. No matter learners are in which application mode, they will directly interact with the learning robot (DLC) while engaging in learning activities using more natural and intuitive method instead of the keyboard in u-ONE system. On the other hand, instructor will have a control station including mobile computing device, mobile output device and wireless local network which are implemented by the laptop.

By examining the architecture of u-ONE System, it can be subdivided into two parts, hardware (Fig. 2(b)) and software. Let's now takes the instruction mode as an example for further explanation. The control station and all learning stations are interconnected through Wi-Fi in instruction mode. Learning robot and RFID reader are connected to learning station. The RFID tags are attached to physical learning materials given to the learners. In Fig. 2(b), the information of learning material stored in RFID tags will be retrieved by RFID reader. The learning robot makes some movements, shows some brief information on its screen, and utters corresponding sound effects depending on what information is retrieved. The u-ONE Software has two agents (control and coordination) and five modules (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 networking about information exchange. Next, the control agent takes over the follow-up operations for the activated modules.

Instructor can adopt u-ONE System in the physical classroom to facilitate learners' comprehension of instructional contents realizing the concept of learning by doing. Instructors could get the learning results about learners in real time, like the error rate of learners' answers, and be aware that if there is any learning difficulties experienced by learners. In order to provide the advantage of this kind of instructional scenario, the logical flow of instruction mode is shown in Fig. 2(c). At the beginning, coordination agent senses the instruction mode has been activated and starts the networking for information exchange. Next, it will initiate all five modules and inform control agent to take over the follow-up operations. The u-ONE Software runs on both the control station (Fig. 3(a)) and the learning station (Fig. 3(b)). Instruction, notification and presentation modules will be initiated and enabled in the control station for instructors. Learning station in this mode would be under instructor's control to give learner related learning materials and guide their learning process. Learners study on learning materials with u-ONE Software supports can get rid of complicated keyboarding and watching computer screen all the time. The tasks of learning activities such as the answer input could be completely done by interacting with learning robot and using RFID. Furthermore, notification module is also enabled to instructor for analyzing, summarizing and sorting of learners' answers, feedback, and scores, etc, at the control station automatically. The control station here provides three functions. First, the application mode switching process will be handled properly to fit with the current learning scenario. Second, delivery of the learning materials to learners is handled by instruction module, like the questions instructor asked and the answers learners responded. And last, the presentation module, displays the summarized information from the notification module at the control station like the statistics result, pie chart and other visual presentation for instructor; Simpler information than instructor's displayers for learners.

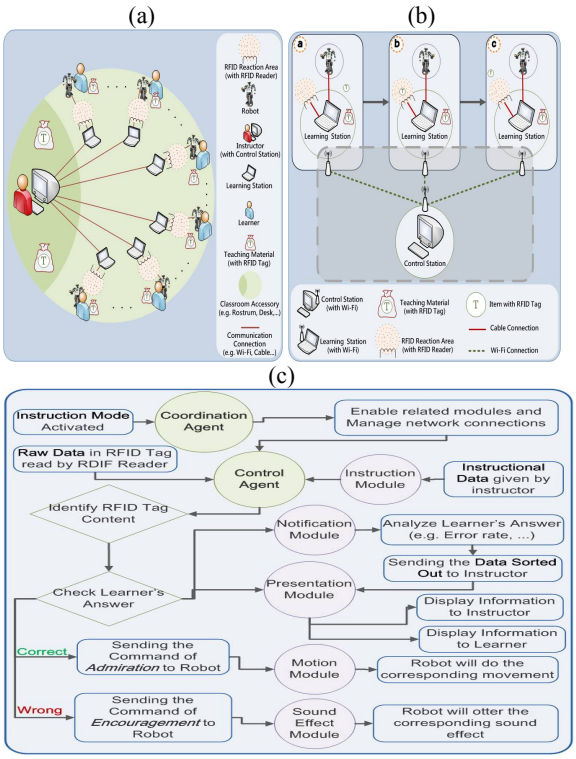

Figure 2. u-ONE System's (a) Sketch map; (b) Hardware process and connection (c) Instruction mode

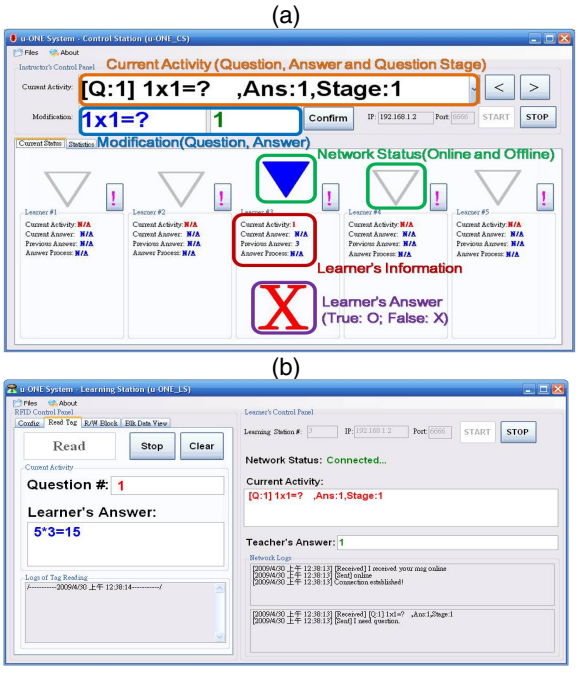

Figure 3. (a) Control station (u-ONE_CS); (b) Learning station (u-ONE_LS)

V. EXPERIMENT OF USING U-ONE SYSTEM

The experiment subjects are fifteen second grade students (seven female and eight male) drawn from three different classes at an elementary school. There are five students in each round from the same class. The duration of the experiment is forty minutes per round which is equal to the time of a normal class. In order to retain details and maintain good quality for observation during learning process, the maximum number of participators per round is limited to five. This research adopts the observation method and questionnaires for data collection.

The comprehension of number in mathematics is especially required to present with physical learning materials for younger learners. In u-ONE System, physical learning materials can produce more easily than ever and they also contain electronic information for further application by attaching RFID tag to something off-the-shelf. The learning contents of this experiment are designed for the multiplication of mathematics and mostly followed the official textbook with some minor adjustments. Instructor can use the built-in instructional material for conducting learning process. Besides, u-ONE Software also provides a flexible and friendly user interface for changing questions and answers at control station. The physical learning materials for supporting children's learning about multiplication consist of fifteen RFID tags attached to Chinese checkers. A set of RFID tags are inputted ten numbers (0 to 9) and five symbols ("+", "−", "×", "÷" and "=") in advance for answering. Moreover, u-ONE Software can record the detailed logs about the calculation processes of learners. For example, instructor gives learners a question "3x3=?" and let them answer this question by using learning robot (DLC) and RFID tags. During answering the question, instructor could ask learners just answer the final answer which is equal to 9 or the whole calculation process which is represented as equation "3x3=9". This flexible log function is very important for children while learning. Because some of learners may not truly understand how to calculate the multiplication and get final correct answer, they might use addition to calculate the result such as "3+3+3=9" for alternate. When u-ONE Software logs the whole calculation process, instructor could locate learners who have trouble with learning multiplication and give them proper and timely assistances.

The experimental procedure is shown in Fig. 4. First, instructor gives the physical learning materials with RFID tags which contain information including ten numbers and five symbols to every learner. Control station of instructor has already prepared the item-bank database about learning multiplication. Besides, every

learner got a learning station which includes mobile computing device (laptop), learning robot (LEGO MINDSTORMS NXT), and RFID reader. The u-ONE Software handles the whole information processing in the background. Then, instructor made an introduction to learners about how to use the system in the first five minutes. Instructor begins to make instruction for learners about multiplication of mathematics. In the next stage, all available instructional strategies could be used for instruction. Learning by doing with sufficient practice time for learners will have positive effects for learning and knowledge construction [1, 2, 5, 6, 12, 18]. In this experiment, physical learning materials are used to practice calculating the multiplication questions for learners. This is the goal of the developed u-ONE System as well. Instructor could ask some questions about the conceptual knowledge of the learning contents just instructed. The DLC and RFID tags would be their answering object and tools. Learners could try to input their own answer or calculation process of the question several times. In such kind of design, every learner in the same learning environment, u-ONE System, would have the fair opportunity to truly practice and participate. At the same time, instructor would receive the information of learners' learning statuses. One part is the raw data recorded as detailed logs about all learners' learning statuses. It could be used for the post analysis about learners' learning after learning activity. The other part is the reorganized information that refined the most important information about learners such as the accuracy of answering questions. With these feedback, instructor could immediately adjust the instructional strategies while the learning activity is still ongoing. Moreover, instructor could also utilize the detailed logs for analyzing learning obstacles of each individual learner and make different assistance to fit each one. While instructor completed the instruction and asserted learners' learning outcomes had achieved the instructional goal, the learning activity was then ended.

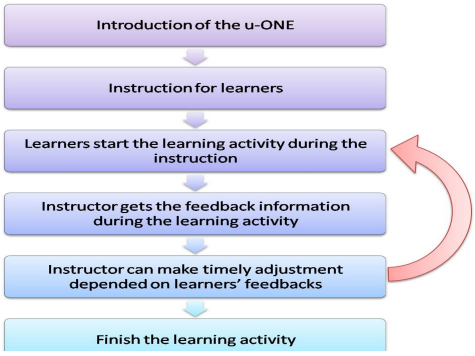

Figure 4. Experimental procedures

When the whole experiment was completed, a simple questionnaire was given to participants, the fifteen learners, for obtaining their feedback and perceptions. The questionnaire has four parts including constructivist learning, experiential learning, joyful learning and sustainable use. The first three parts are all compared with previous learning experiences. These four parts are designed to collect the perceptions and feedback from learners for this research's three constructs and future development. This questionnaire adopts five-point Likert scale for scoring. While all learners completed the questionnaires, the result of descriptive statistics is shown in Table II. The results show the mean score of each question item are all higher than 4.40. This implies that learners are very satisfied with using the u-One system. According to the results and positive feedback from learners, the effect of u-ONE System has been successfully revealed and supported.

TABLE II. ALL LEARNERS' RESPONSES OF DESCRIPTIVE STATISTICS

Item#	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Valid N	15	15	15	15	15	15	15
Mean	4.47	4.40	4.80	4.80	5.00	4.93	4.93
SD	.834	.828	.414	.561	.000	.258	.258

VI. RESULT AND DISCUSSION

Before this experiment started, there is about one hour period for preparation. Two parents are followed the director of general affairs to visit this experiment and tried to use the u-ONE System. Their children did not participate in this experiment. After the introduction to them, they showed their high interests in this research and hoped to make a reservation for their children to participate next time if possible. However, they also expressed their concern that current setting in this experiment using RFID tags for simple numeric answer input might take too much time than directly writing down on the paper in the class. Perhaps this concern exists from the viewpoint of adult, but RFID tags will bring the benefits when the learning contents become more complex and have difficulty for the input such as keyboarding to children. For example, a course is to recognize different animals in the zoo, the pre-inputted information in RFID tags could make learners quickly obtain animals' information like their species by mobile devices and make these as some kind of notes.

During the experiment, instructor plays a support role for conducting the learning activity at proper moment. Generally, learners can easily and quickly

learn how to use the u-ONE System. The ease of use is proved by this observation as well. At the same time, it also evidenced that the setting of u-ONE System would not bring too much ICT use burdens to learners, especially for the children. In the experiment, when instructor gave an exercise to learners, learners were all excited to practice it. Instructor can get the immediate learning statuses form the u-ONE Software at control station. So the instructor could make more precise decision for guiding the learning activity and provide more suitable and prompt assistance for those learners who need help. Because the behavior of learners is quite active, enthusiastic and joyful, the interactions among instructor and learners can be regarded as being well improved. Besides, there are two learners asked interesting questions. One asked, "May I bring the DLC home after experiment?" The other one expressed, "I will ask my parents to buy one for me." According to the responses of two learners, learning motivations of learners have been successfully aroused. While learners have higher interests and joyful perceptions during the learning process, the outcome will bring higher learning motivations to them. The result is the expected goal of u-ONE System. It also evidences that u-ONE System can provide a joyful learning to learners. Moreover, every learner in u-ONE System can practice on his/her own and then reflect the learning contents with instructor's support for knowledge construction. Hence, these completely match with the core concepts of experimental learning theory, constructivist leaning theory and joyful feature from the result of this experiment.

Next, a mail survey was executed for three instructor subjects (IS_A, IS_B and IS_C). The instructional experiences of IS_A, IS_B and IS_C are "2 to 3 years", "1 to 2 years" and "about 1 year." The reason of choosing younger instructors for this experiment is that they could more easily and possibly accept the ICT applications applied into the practical instruction and learning. This survey consists of five parts uses the open-ended questions to answer.

In the constructivist learning part, they all think learners in u-ONE System who solely use present u-ONE Software cannot make greater progress for reflection than conventional learning method without instructor's assistance. The design of u-ONE System has considered this question and provides three application modes for different scenarios. For example, instructor exists for learners to conduct them reflection in u-ONE System with instruction mode. However, learners might not make better reflection on their own in some learning scenarios like the self-learning mode in present u-ONE System. There are some aspects needed to improve. One of the possible improvements is to develop adaptive learning function for u-ONE Software. With the function of adaptive learning, learners could receive proper assistance and learning materials automatically during the learning process.

The responses of experimental leaning and joyful learning are both positive. They state that learners in u-ONE System would have practical exercises on their own and joyful perceptions during the whole learning activity process. Besides, u-ONE Software would log detailed learning statuses and some most important and brief information are presented for instructor immediately during the learning process. When learners feel happy and enthusiastic during the learning process, most of them would arouse their learning motivations and concentrate on the learning activity. The result would bring the positive effect for instruction and could facilitate instructor to control the behaviors of learners such as some elfish children. Nevertheless, the instructor subject IS_A infers that some learners might lose their concentrations over time. The possible improvement is that a long-term experiment could be executed for more in-depth research in the future.

In the assistant instruction part, they all think that they feel the learning attitudes of learners are more positive than prior conventional learning method. They also can obtain sufficient learning statuses of learners in u-ONE System. In addition, the functionalities and stability of u-ONE Software and hardware still need to be improved for the more assistances and shorter response time to learners. In the last part, the opinions of sustainable use were collected. They all agree that the thought and concept of u-ONE System is a quite good idea and design for assistant instruction and learning. This experiment is just an example for the demonstration of u-ONE System. Some other learning activities, for example English words learning, could be implemented as the plug-in functionalities of u-ONE Software as well. The whole concepts, designs and developments of u-ONE System with u-ONE Software have been elaborated in this research completely.

VII. CONCLUSION

The aim of this research is to design and develop a prototype of u-ONE System including hardware and software components for supporting children's learning by using robot and RFID. The main constructs of this research are experiential learning theory, constructivism learning theory and joyful learning feature. Based on the three constructs, the concepts, designs and implementations of u-ONE System are being developed. A preliminary evaluation of the system was also completed in this research. The five key and essential elements would construct the hardware part of u-ONE System. In the background, u-ONE Software plays the software part for supporting

the holistic system managements such as operations, connections and processing in u-ONE System. Then, appropriate instructional strategies and pedagogies would be brought by instructors to conduct the instruction and learning activity. The developed u-ONE System can support three application modes which are (a) instruction mode; (b) collaborative learning mode; (c) self-learning mode. In the final stage of this research, a preliminary evaluation was conducted in the real world. The results show that most learners in u-ONE System could arouse their learning motivations and help them concentrate on the instruction and learning activity. The class order was found to be improved a lot such that instructor can manage learners' behaviors much easier during the class.

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