TANGIBLE OBJECTS: THE MISSING ATTRIBUTE IN MULTIMEDIA LEARNING SYSTEMS FOR PRESCHOOLERS

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ABSTRACT

Based on the idea of constructivism, cognitivism, Atkinson & Shiffrin and Kieras & Meyer's EPIC human memory theories, tangible objects are considered the missing attribute in digital multimedia learning systems for preschoolers. Because of negligence to this attribute, a learning gap emerges between preschoolers and multimedia system. The gap is reflected in the cognitive capability of a preschooler whose cognition is still in a state of preoperational level and the condition of multimedia which only delivers information in digital visual-auditory format. In light of the four compelling theories, a multimedia prototype augmented with the use of tangible objects named "TangiLearn" has been designed. In this paper, we begin our discussion by visiting the idea of tangibility brought forward by the theories, followed by a relevant pilot study to illustrate a successful innovation in closing the learning gap.

KEYWORDS

Tangible object, Multimedia, Tangible Multimedia, Preschoolers

1. INTRODUCTION

Recent years have observed remarkable advancement in ICT, particularly in the field of the human-computer interaction (HCI). *iPad*, a line of touch-screen tablet computers, has emerged as an innovation that greatly facilitates intuitive HCI in the delivery of digital information. With *iPad* in hand, preschoolers interact with the computer naturally using finger. Many multimedia learning systems for preschoolers have followed the pace of *iPad* where touch-screen is also adopted in aid of teaching and learning. In fact, there exists an inconspicuous problem in multimedia learning. Preschoolers are in a category where much behavior is described by its own specific characteristics. They are said to be in a state of preoperational level where their mental structure on which all subsequent learning attained is highly dependent on external concrete stimuli [1][2]. In addition, they have limited vocabulary and unskilled motor acuity [3][4]. Conversely, multimedia only delivers information in digital visual and auditory format. The repercussion for these two opposite ends is a large learning gap between preschoolers and

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multimedia learning system. The gap further deepens consider that most of the instructions nowadays are overwhelmed by huge amount of materials that exceed the young children's learning capacities [5]. For preschoolers who have special nature signified by Piaget [1][2], intuitive interaction observed in *iPad* is insufficient. They need additional attribute that is truly adapted to their cognitive structure. As interaction-friendly innovation does not mean it is cognitive-friendly to preschoolers, thus, a new attribute in digital multimedia has to be sorted out for them.

Figure 1. Missing attribute in digital multimedia environment

Based on the idea of constructivism, cognitivism, Atkinson & Shiffrin [6] and Kieras & Meyer's EPIC [7] human memory theories (*the Theories* thereafter), tangible objects are the attribute necessary for cognitive learning to take place effectively in digital multimedia for preschoolers. Their points of view support the need of physical sensation via tangible objects for preschoolers to grip in order to make sense of the concepts, especially ideas outside of their immediate context [8]. In light of *the Theories*, a new "breed" of multimedia system augmented with tangible objects has been conceived. In this paper, we begin our discussion by visiting the idea of tangibility brought forward by *the Theories*, followed by description of the design of the multimedia, and its implementation during pilot study.

2. TANGIBLE OBJECTS AS AN ATTRIBUTE FOR LEARNING IN *THE THEORIES*

Cognitivist and constructivist theories explicitly rationalize the role of learning activities associated with tangible objects. Piaget's theory of cognitive development [1][2] identifies sensory-motor and preoperational level (where young children aged seven and below belong to) as stages of mental orientation dependent on external concrete stimuli. A similar point of view is shared by constructivists, who state learning as cognitive construction of knowledge [9][10]. Their approach of learning calls for the young children to be as active as possible to self-explore any physical apparatuses in the classroom for learning [11][12].

Atkinson & Shiffrin's human memory theory (ASHM)[6] is the first memory theory that asserts the existence of tactile sensory channel in the process of knowledge acquisition. It postulates that learning is equally dependent on auditory, visual, and tactile sensory channels. Accordingly, in the course of a learning process, information is first registered in the three sensory channels before they are transmitted into short-term store (STS). STS is a pure storage platform that has severe limitation in its capacity. If the information is repeatedly rehearsed, it can be transmitted to long-term store (LTS) permanently (Figure 2). Information not transferred to LTS will decay with time quickly [13][14].

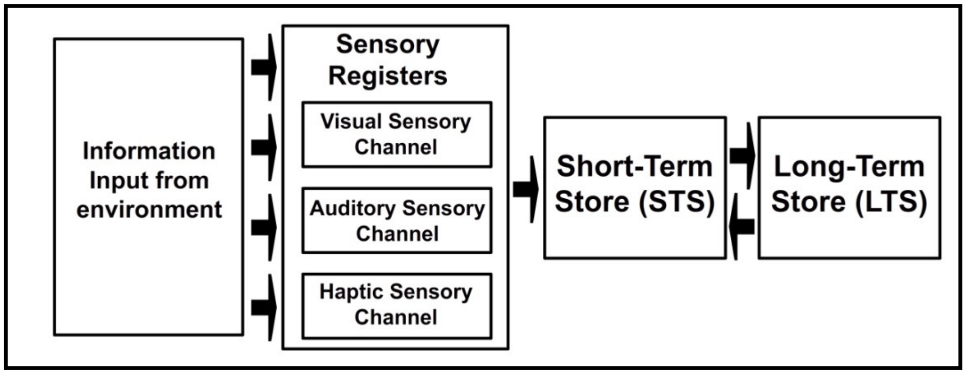


Figure 2. Atkinson & Shiffrin's human memory theory (adapted from [6][13])

EPIC (Executive Process-Interactive Control) framework [15] is by far the most comprehensive human memory theory on tactile information. Its theoretical viewpoint covers not only the flow of tactile information, but also the concept of multiple levels of tactile related components in memory system. EPIC asserts that human cognitive structure is made up of a central cognitive processor (consists of working memory and long-term memory) surrounded by three peripheral perceptual processors (visual, auditory, and tactile perceptual processors) and three motor processors (vocal, manual and ocular-motor processors). Perceptual processors are in charge of registering stimuli input from senses whereas motor processors are responsible for moving different effector organs (eyes, hands, and vocal organs). All these processors operate independently, but can be simultaneously or asynchronously in parallel with each other. Figure 3 illustrates the overall organization of the EPIC framework. Types of memories are delineated in rectangular boxes whereas perceptual and motor processors in oval boxes. Information flow paths are represented using solid lines and connections using dashed lines.

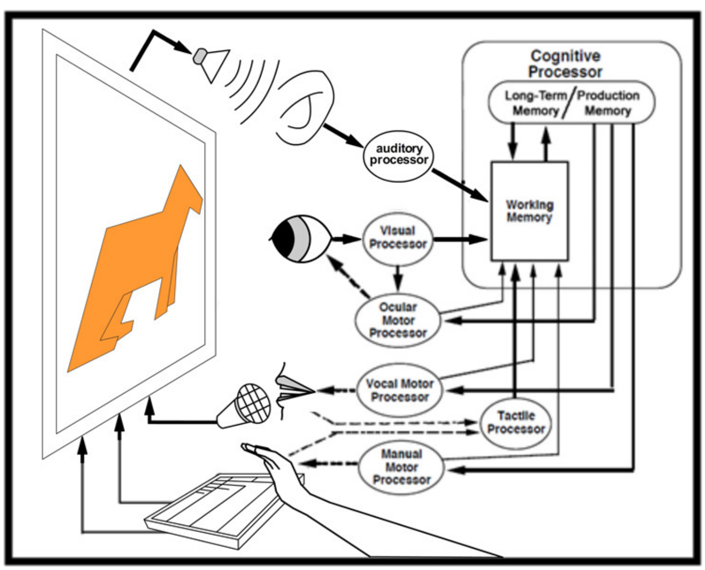


Figure 3. Overview of EPIC framework (adapted from [16])

According to EPIC, the operation of human cognition begins with perceptual processors. They receive visual information from eyes, auditory information from ears, and tactile information from hands. The information received will then be channelled into cognitive processor. Cognitive processor may generate commands to motor processors to trigger relevant sense organs. For example, after accepting visual information, it will command manual motor processor to move hands, or ocular motor processor to move eyes to perform further examination on the object. At the end of the process, the motor processors may establish feedbacks to cognitive processor.

Overall, *the Theories* shed light on the fact that multimedia learning system should embrace tangible objects for preschoolers' multimedia learning.

3. TANGIBILITY AS A COMMON ASPECT IN *THE THEORIES*

Discussion above reveals that the idea regarding the role of "tangibility" of tangible objects is the aspect that *the Theories* have in common. We adopt the term "tangibility" from Ullmer and Ishii's Tangible User Interface (TUI) researches instead of tangible objects because TUI systems have been well researched for the past 16 years [17] [18] [19]. The intersection area illustrated in Figure 4 indicates the commonality of the theories. The dashed lines denote other similar aspects between *the Theories*.

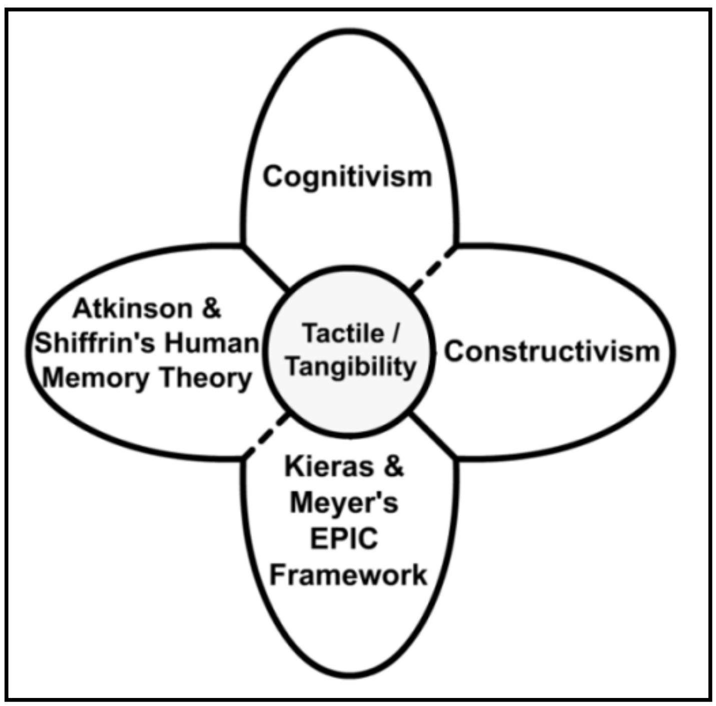


Figure 4. Common aspect in constructivism, cognitivism, ASHM and EPIC

The commonality denoted in the intersection area implies the missing attribute in multimedia learning systems for preschoolers. With tangible objects added to multimedia realm, *the Theories* discussed above can be fully implemented, as illustrated in Figure 5.

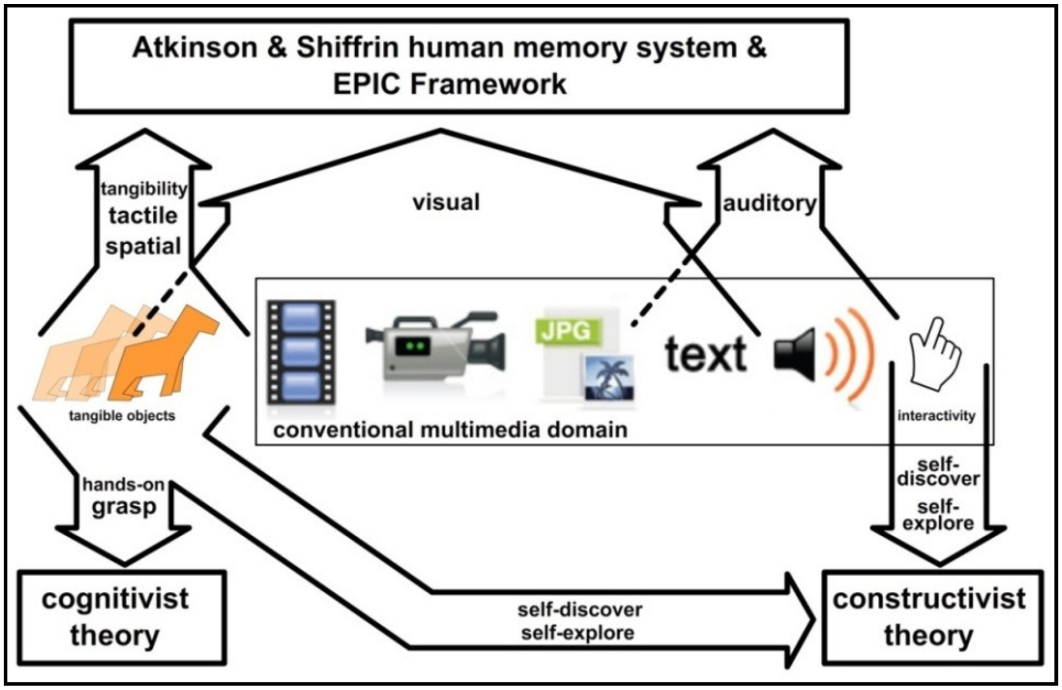


Figure 5. The application of the four theories in tangible multimedia

4. PILOT STUDY: PROPOSING TANGIBLE MULTIMEDIA (*TANGILEARN*)

Based on the idea of commonality in cognitivism, constructivism, ASHM and EPIC theories (*the Theories*), we conceive a multimedia learning system that embrace the sense of tangibility for preschoolers. We propose to term such multimedia as "tangibility augmented multimedia learning system", or in short, tangible multimedia. To gather preliminary evidence about the feasibility and pedagogical value of such multimedia prior to actual experimental research [20], we developed a relevant prototype of tangible multimedia named *TangiLearn* for pilot study.

4.1. Design of *TangiLearn*

TangiLearn is designed with the target to realize the aspect of tangibility prescribed in *the Theories*, on a par with visual and auditory information in digital multimedia.

The architecture of *TangiLearn* is illustrated in Figure 6. *TangiLearn* comprises two arenas, namely physical arena and virtual arena. Physical arena consists of a display table, speaker, mouse, keyboard, monitor, CPU, and an array of tangible objects whereas virtual arena composed of virtual learning objects and background scene.

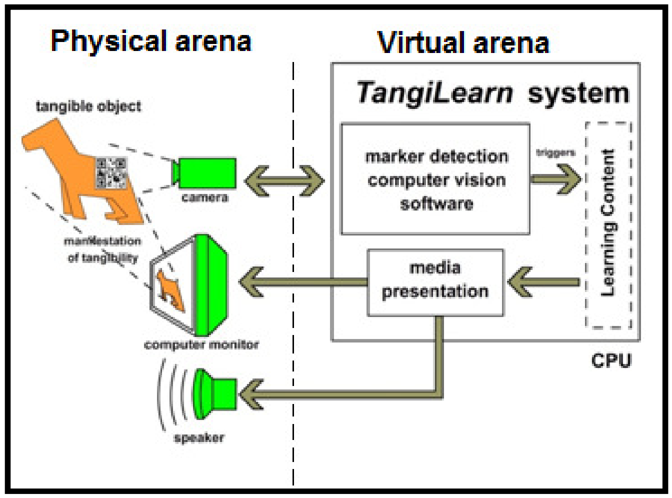


Figure 6. *TangiLearn* system architecture

TangiLearn is designed in a way that virtual arena is "surrounded" by many tangible learning objects such as dolls, spoons and bags randomly placed in physical arena (Figure 7).

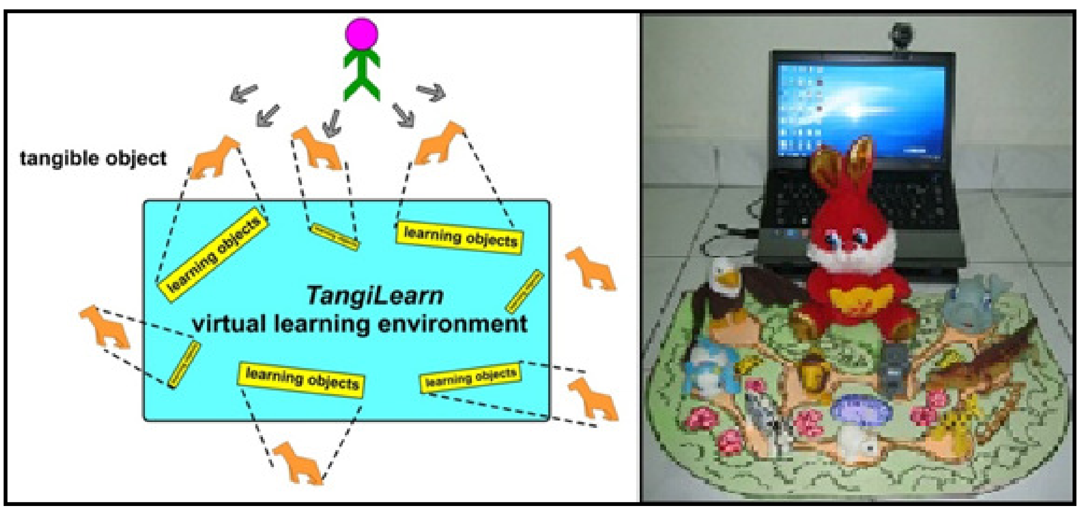


Figure 7. *TangiLearn* tangible and virtual arenas

Two conditions have been taken care to ensure *TangiLearn* is cognitive-friendly rather than interaction-friendly to preschoolers. First, unlike TUI systems, tangible objects in *TangiLearn* are deployed as the target objects for the preschoolers to learn. In TUI systems, tangible objects are utilized as a natural form of interface to facilitate better interaction with computer [21][22]. For *iPad*, although holding it in hand may give preschoolers a sense of tangibility, it is not rightfully a tangible object because *iPad* is not in any form of metaphor or representation for any digital information presented on computer screen [23]. Furthermore, its tactile information is different to real-life tangible objects. Like TUI systems, *iPad*'s intended target is to provide an intuitive interface for human in the delivery of digital information, rather than an entity of learning.

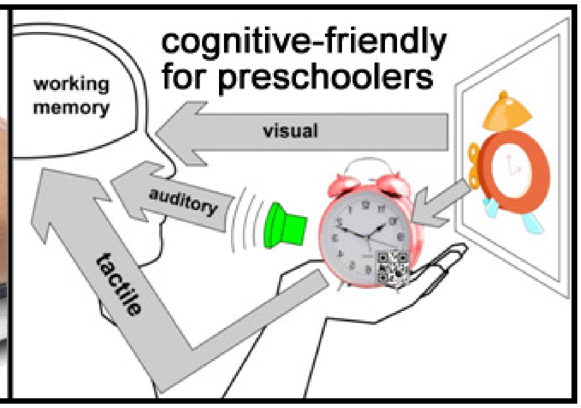


Figure 8a. *iPad* Figure 8b. *TangiLearn*

Second, direct representation of tangible objects is manifested in *TangiLearn*. This means tangible objects are not used to represent other domain. Instead, they represent themselves. We directly map tangible objects into the virtual arena. If tangible apple is used, it is apple in the virtual arena. By doing this, we "concretize" the virtual learning objects, which capable of giving the illusion to the preschoolers that the virtual object can be felt and grasped. According to Uttal, Scudder, & DeLoache [24] and Manches [25], young children have problems to interpret symbolic and abstract representation. In *TangiLearn*, the preschoolers are expected to learn the tangible objects in English as second language (e.g. able to spell and read the name and key terms of the learning objects).

Figure 9. Concretizing virtual learning object in *TangiLearn*

As a newly explored area, we have problem to find one framework for the structure of tangible multimedia as a guideline for development. To overcome this problem, we divert our focus on the application of our proposed framework for tangible multimedia [23]. Compliant with the framework, all multimedia objects, including tangible objects in *TangiLearn*, are set equally important, and significantly used in a way that they complement each other meaningfully to achieve the overall tangibility experience.

The learning process in *TangiLearn* starts when a preschooler grabs a tangible object, and points it to the webcam to trigger the virtual learning object to display corresponding animations and videos about the object on the computer screen. During the pilot study, the tangible and multimedia objects binding were implemented through the adaptation of QR code and Flash library in *ActionScripts* 3.0. Each tangible object was glued with QR code visual marker for system recognition. QR code technology was chosen because it entails minimal monetary investment.

Upon the last learning object reaching its end, quiz and problem-solving questions will be followed. Similar to learning session, the preschooler would need to answer the quiz and solving problems by identifying and picking up the correct tangible object. Problem-solving section is designed to determine that tangible objects in multimedia context are able to develop the background knowledge and skills necessary for preschoolers to move to a higher level of cognitive reasoning. Compliant with the idea of Gelderblom and Kotze [26], several scenarios are created. The preschoolers are not only required to know when and how to apply what they have learned, but also to deal with the problems they may encounter in everyday life confidently. One typical example of the problem-solving question is shown in Figure 10 [27].

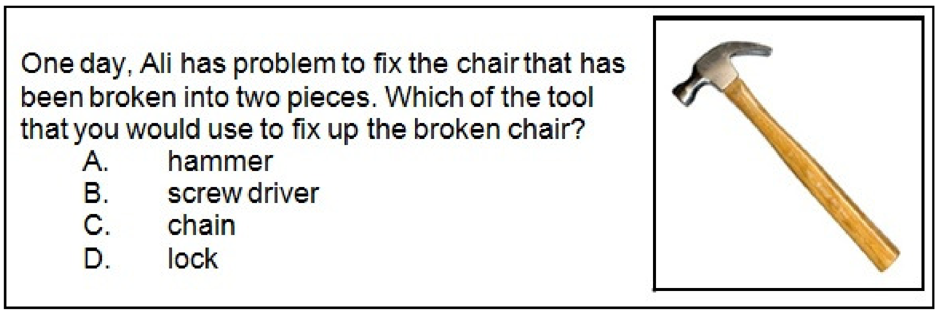


Figure 10. A sample question of the problem-solving section in *TangiLearn*

For this question, the preschooler will have to answer using correct tangible object, in this case the hammer. The camera will detect the tangible objects presented by the preschooler, and respond accordingly. With concrete experience of the tangible hammer in hand, they gain better the concept of hammer, and thus could use it correctly. The preschooler's ability to solve problem implicates that they have comprehended the object they learned.

The whole learning flow in *TangiLearn* is designed in cyclical sequential format that the preschooler starts from tangible objects exploration, followed by presentation of multimedia contents for conceptualization, and then the reinforcement of the concepts by participating in problem-solving and quizzes associated with tangible objects (Figure 11). This is to ensure permanent acquisition of knowledge in their memory. To avoid cognitive load imposed on the young preschoolers, problem-solving questions were embedded within quizzes.

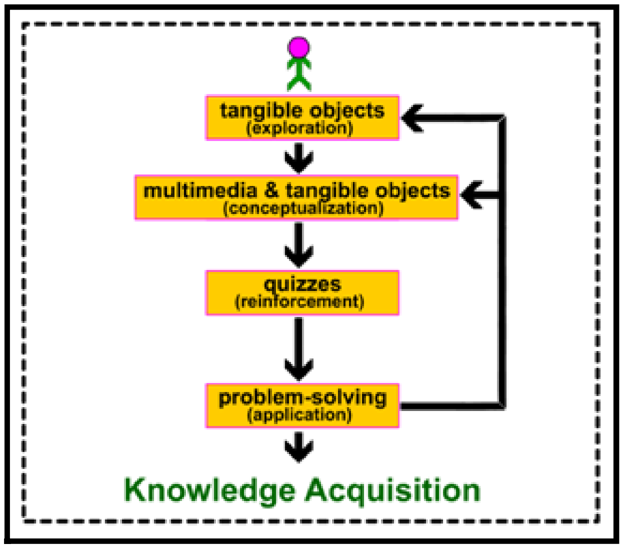


Figure 11. Learning process in *TangiLearn*

4.2. Finding of the Pilot study

Six preschoolers aged six from a Malaysian kindergarten were chosen as the evaluators in the one-day pilot study. Unstructured observation and Questionnaires (*Smileyometer* and quiz) were employed to elicit ideas pertaining to the usefulness of the *TangiLearn* from the evaluators.

Observation revealed that the most attractive feature in *TangiLearn* to the young evaluators was not animations or videos, but the tangible objects. Because of tangible objects, the evaluators were curious to know the contents each learning objects were to deliver. They deliberately explored the tangible objects arranged in front of them. They tinkered with the tangible objects and attempted different positions and alignments to the computer. None of the evaluators indicated that they wanted to stop prior to completion of the allocated amount of time for learning in the learning session.

The quiz results showed that the evaluators learned the tangible objects from the system. Out of 15 questions, 3 participants obtained more than 75% of marks (distinction) after treatment using *TangiLearn*. Physical sensation of objects was believed to have enhanced their working memory and long-term memory as they were able to solved problems as well as recite well the key terms learned from the system.

Table 1. Evaluators' Performance in Pre-quiz & Post-quiz

Type of quiz	Distinction	Merit	Pass	Fail
	No. of evaluators			
Pre-quiz	0	0	6	0
Post-quiz	3	3	0	0

Smileyometer [49] were used to gauge the participants' level of enjoyment respectively. We adopted the idea of Zaman and Abeele [50], and referred the enjoyment to "joy-of-use" or "likeability" of using *TangiLearn*. The self-report instrument was made child-friendly by the use of smiley, a pictorial representation of different kinds of happy faces to represent the different levels of enjoyment. *Smileyometer* was modified to suit to the level of the participants.

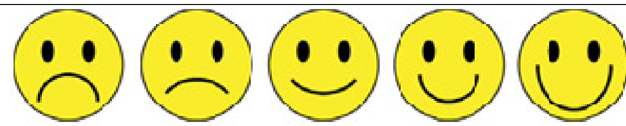
I enjoyed using *TangiLearn* very much.	

Figure 12. An Example of *Smileyometer*

The pilot study (Table 2) revealed that the evaluators generally rated their level of enjoyment of using the *TangiLearn* with the highest score (enjoyed very much) in *Smileyometer,* as shown in Table 2.

Table 2. Results of the *Smileyometer* scores on using *TangiLearn*

	Evaluation Items	**Average**	**Enjoyment Level**
1	I feel comfortable to use *TangiLearn*.	5	Most effective
2	I like *TangiLearn*.	5	Most effective
3	I'm interested in *TangiLearn*.	4	effective
4	I enjoyed using *TangiLearn* very much.	5	Most effective
5	I like the way the tangible objects help me in learning.	5	Most effective

The finding of the pilot study indicated that *TangiLearn* was an educationally valuable and enjoyable system [28]. We believed that iterative hands-on experiences enriched with multimedia expressions contributed to this positive outcome.

4.3. Refinements to *TangiLearn*

Numerous problems encountered in QR code visual marker technology prompted us to explore alternative technology for implementing the tangible-multimedia binding. The most notable problem was related to the issue of physical alignment of markers. Most of the preschoolers have difficulties in orientating the visual markers to the camera precisely [28]. By average, they took 35 seconds to get the visual marker recognized. Considering the choice of technology should rest on its usefulness to the students as learning aids, we decided to refine the implementation by deploying sensors technology, which comprises RFID readers, force sensors, spatial sensors, and electronic sliders in the final experimental research [20]. Because of its cost, they were not deployed in the pilot study. Compared with the past, multimedia developers nowadays have a very wide range of choice in technologies, such as tangible system development toolkits and customizable open source libraries [17][29][30][33], to develop a tangible multimedia system. As the costs, capabilities, and features of the tools are varied, thorough consideration is required for the right selection of development tools.

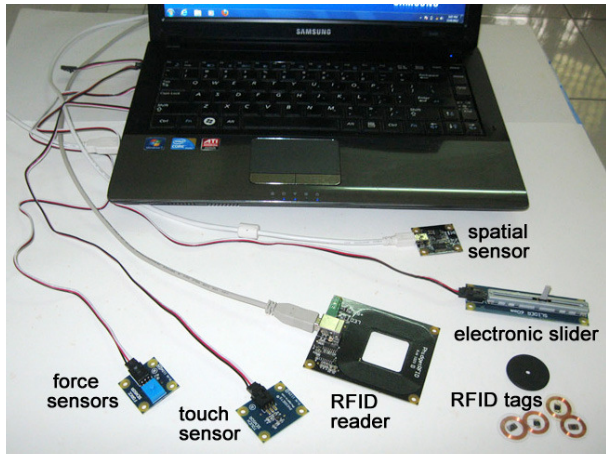


Figure 13. Sensor devices deployed in *TangiLearn*

To overcome the problem of precise alignment, RFID reader and tags will be deployed to identify tangible objects. It is done in a way that RFID tag is inserted into a tangible object. When the tangible object is moved towards the field of radio wave generated by a compatible reader, the tag will transmit the identification information to the reader, thereby establishing mutual communication that allows the computer to identify the object (Figure 14).

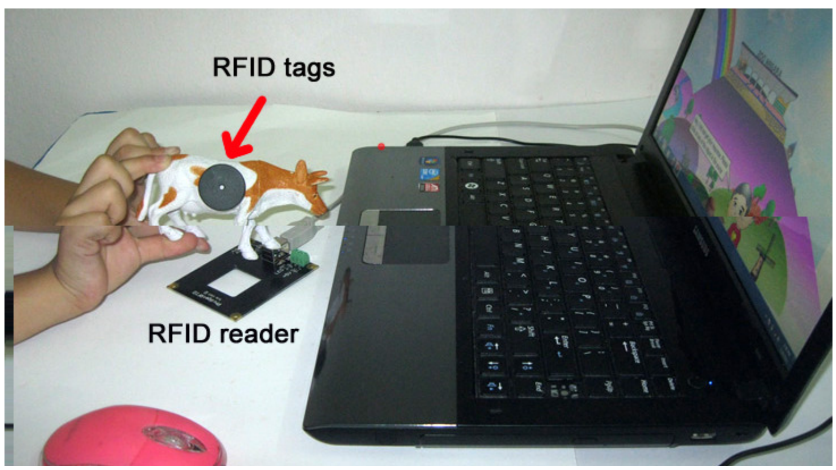


Figure 14. Implementation of RFID reader

We believe that the sole deployment of RFID reader is insufficient if we wish *TangiLearn* to deliver a stronger sense of tangibility to the preschoolers. Therefore, we deploy electronic slider, force and spatial sensors interchangeably. For electronic slider, a tangible object is attached to its handler (Figure 15a). By grasping and moving the object, the preschooler is to move the virtual learning object. For force sensor, it is glued on tangible object that requires pressing (Figure 15b). The more the preschooler presses the sensor via the tangible object, the more the virtual learning object responses.

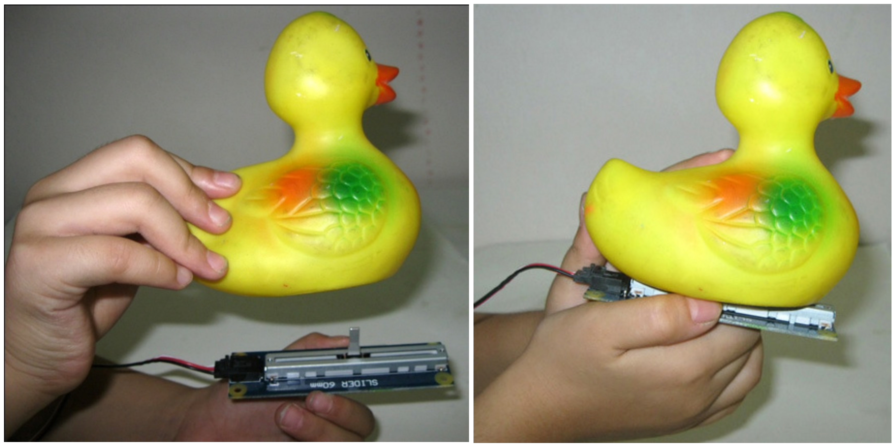


Figure 15a. Electronic slider

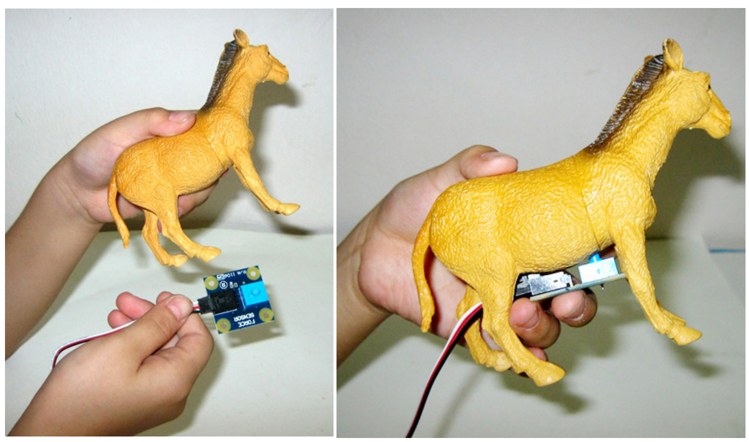


Figure 15b. Force sensor

Spatiality is human innate ability to interact with concrete objects in physical space [31]. As tangible objects are a logical choice for spatial activities [32], thus spatial movement is made possible in *TangiLearn*. We plan to deploy spatial sensor attached on tangible objects for this purpose (Figure 16). By performing simple hand movement and gestural operation suit to the preschoolers' level of mental structure and motor acuity, corresponding virtual objects will be reacted accordingly.

Figure 16. Implementation of spatial sensor in *TangiLearn*

Although different types of sensor devices are used, they are converging and deployed in complementary ways to deliver multimedia contents. In response to the changes made on the technology used, we redesign some of the learning session so that the integration between learning objects in physical and virtual arenas can be done more seamlessly. For this, we add cooking, sewing, and drawing sessions in *TangiLearn* learning session. Acquiring know-how to cook, sew, and draw is not the final objective of the session, but to understand the real objects involved, how and when they are used in the cooking proces. For example, in cooking session, the preschoolers are expected to learn the ingredients required in cooking. When "Add Mayonnaise" text is displayed on screen (Figure 17a), the preschooler will be required to identify and pick the tangible mayonnaise embedded with RFID tag, and point to the RFID reader. If the preschooler picks incorrectly, a wrong message will be highlighted. If the child picks correctly, the virtual mayonnaise will be animated, and slowly moved towards the virtual frying pan (Figure 17b).

Figure 17a. Cooking session

Figure 17a. Moving virtual mayonnaise

Subsequent step for the preschooler is to learn more real objects, namely condensed milk, lemon juice, and macaroni (Figure 18a). All their corresponding tangible objects are embedded with distinct tags for identification. After all ingredients are "poured" into the virtual frying pan, a virtual stirring spoon will be shown (Figure 18b). This indicates that it is time for the preschooler to identify the tangible stirring spoon, which is augmented with spatial sensor. After picking up the tangible spoon, the child will need to perform simple hand movement detectable using spatial sensor. As a result, a simulation of the stirring action will be played in *TangiLearn*. Using this method, the preschooler not only learns the relevant key terms, but also the role of ingredients and tools in food preparation.

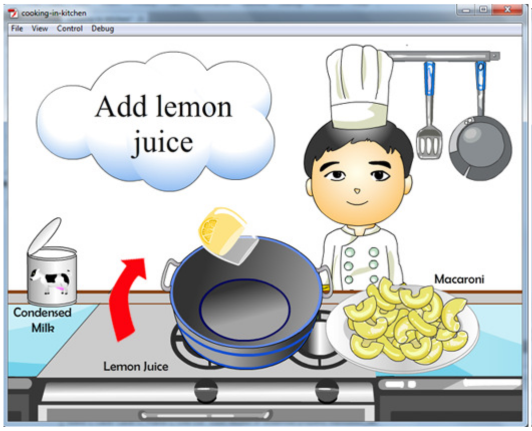


Figure 18a. Moving lemon juice   Figure 18b. A stirring spoon displayed

Based on *the Theories*, design and setting of *TangiLearn* discussed above potentially bridge the gap faced by the preschoolers in multimedia learning.

5. CONCLUSION

At the outset, *TangiLearn* poses several limitations that may affect its efficacy. The most notable limitation is related to the wired connection between tangible objects and computer. The lengthy sensor cables not only restrict the mobility of tangible objects, but also lead to a situation of physical clutter and confusion in display. Another limitation is related to the choice of tangible objects. It is obvious that materials in liquid and gaseous form are not feasible in *TangiLearn*. Using toys to represent them may be workable but the tactile information provided by the toys is different. Furthermore, the use of toys may divert the preschoolers' attention from actual learning, and ended up playing around with the toys. Other than that, huge tangible objects may take up a large portion of space in front of them and subsequently block their view to the computer screen. Small tangible objects are weak in sense of tangibility. On the same note, due to the narrow scope and range of tangible objects possible for use, generalization of the *TangiLearn* to other genre of multimedia systems such as games and virtual reality applications is restricted.

Despite the limitations, tangible objects are still worth introduced into the multimedia landscape considering the strength of physical affordances prescribed by constructivist, cognitivist, ASHM, and EPIC theories. Besides having strong theoretical base, the positive result in the preliminary pilot study also gives an overview of the capability of tangible multimedia in solving the learning gap between preschoolers and multimedia systems. We wish there will be more research efforts on tangible multimedia to overcome the above limitations. The design of the working prototype of tangible multimedia, *TangiLearn* system is still very rudimentary, and requires continuous improvement. As real adaptation of tangible objects into multimedia learning has not taken place yet, a full scale experimental research on its efficacy is thus currently planned and underway to evaluate the potential of the system thoroughly [20].

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