Collaborative Augmented Reality in Education: A Review

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***Abstract*—Globalization and innovation in technology have led to the extensive use of the latest technology in almost every sector, and education is no exception. Different technologies have been employed in various disciplines within the educational sector. Studies have shown that technology can enhance teaching and learning experiences. Augmented Reality (AR) is a new technology with vast potentials and great pedagogical value that offers new methods for education. AR enables the overlaying of computer-generated virtual information into the real environment in real time. Thus, researchers believed that the AR has provided new opportunities for designing engaging learning environments. Although the AR may improve educational outcomes, the main factor is to understand the process of designing the AR to support learning activities. Thus, various instructional strategies such as collaborative learning, were considered when designing an AR learning environment. Collaborative learning permits students to engage with other students and the educational content at the same time, resulting in a deeper understanding and higher motivation. Because educational research concerning collaborative AR is still in its infancy, this paper intends to review the literatures concerning collaborative AR, its previous usages and its potential in educational context.**

***Keywords*—Augmented Reality; collaborative learning; education**

I. Introduction

Information or knowledge acquired by an individual normally occurs through different media. However, the traditional 'verbal' educational method is not necessarily effective [1]. Many studies [2] [3] have testified that students who solely rely on lectures are incapable of recalling ideas, and seem to struggle to solve a given task. Regardless, many educational institutions are still using these ineffective and non-interactive approaches which often result in lack of interest among students. Thus, educators are forced to search for better approaches that can help the students improve their learning experiences.

Learning experience is recognized as an important part of an education system, and can be more meaningful when more senses are involved (sound, sight, touch, emotions, etc.) [4]. Educators are looking to adopt new technologies in their classrooms in order to enhance the learning experience of their students, partly because such methods can easily engage students and improve their academic performances [5] [6].

Nonetheless, concerns over the use of emergent technologies necessitated the continuous monitoring of students' motivations during learning activities. So far, different technological tools have been utilized in educational settings to deliver the course content; among the examples are computers, the internet, e-learning, social websites, semantic websites, learning objects, simulations, games [7][8]. Recently, the emergence of the augmented reality may possibly leave an impact on the teaching and learning process as well as offer new ways to educate.

Nevertheless, compared to other technologies such as multimedia, games and online learning, the implementation of AR in education is still at its developing stage. Although AR has demonstrated vast potentials, educators still need to understand how to design AR in order to make enhanced learning experiences affordable [9].

A variety of instructional strategies that take advantage of the AR affordances are available. For example, collaborative learning has been used to design AR learning environments. However, too little attention has been paid to collaborative AR and hence, this paper intends to review the literature concerning collaborative AR learning, how it was used in previous researches and its potentials in the educational field.

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II. METHODOLOGY: DATA SOURCE

To achieve the purpose of this article, we have searched numerous electronic databases for articles published between 2000 and 2013. The following combinations of keywords were used to research: augmented and mixed reality, collaborative learning, and education. Conference papers from the IEEE databases and Google Scholar were also included to help identify related publications. Next, we selected publications pertaining only to collaborative AR learning and related educational issues. Finally, in-depth reading, discussions and notes were taken on key points derived from these publications in order to answer the research questions.

III. AUGMENTED REALITY

Augmented reality (AR) refers to a system that projects computer-generated objects such as texts, images, videos and 3D objects onto a user's perception of the real world. Currently, the term AR is defined differently by researchers. Early on, its creator [10], has defined AR as a situation where users can view a combination of virtual and real world objects, in real time. Furthermore, [11] as well as [12] and [13] have characterized AR systems by three properties: (a) combination of real and virtual objects, (b) interactive in real time, and (c) 3D registration of the virtual and real objects According to [14], AR could also be broadly defined as a technology that allows the computer to generate a virtual element to be superimposed on physical objects in real time.

Moreover, an augmented reality (AR) is closely-tied to a virtual reality (VR), because AR is believed to be a variation or extension of VR [11]. Both systems share common features such as interactiveness, immersiveness, being information sensitive [15] and allowing navigation [16] [17]. On one hand, the VR technology completely immerses a user into a synthetic environment. In the VR world, the user cannot see the real world around him/her. On the other hand, the AR technology allows the user to see the real world environment with the virtual information overlaid upon it.

According to [18], there are two taxonomies of AR application in terms of development: (a) marker based AR and (b) markerless AR. Generally, a marker-based AR requires a marker to register the position of a virtual object to be displayed into the users' perceptions of the real world. The marker based AR may operate on five items: (a) computing device such as laptop and desktop, (b) software, (c) marker label, (d) web camera and (e) display device such as a computer screen or a projector. By detecting the marker label through the web camera, the virtual object can be displayed on the computer screen. In contrast, markerless AR relies on any part of the real environment as the target to project a virtual object. It operates by incorporating a global positioning system (GPS) that identifies coordinates or locations. Then, the GPS will deliver the computer-generated information to those coordinates.

IV. COLLABORATIVE LEARNING

Collaborative learning is a situation in which two or more individuals work or learn together to achieve a common purpose [19]. Unlike individual learning, people who engage in collaborative learning are responsible for both their own as well as their colleagues' learning [20] [21]. Meanwhile, [22] has observed that active interactions, evaluations as well as exchanging ideas and experiences in collaborative learning settings have increased students' interests while enhancing their critical thinking. Recently, this situation has changed dramatically. The advancement of computing technology has made it possible to expand collaborative learning. Information technology is used to facilitate communication and collaboration between i) teachers and students and ii) among students themselves. This method is known as a Computer-Supported Collaborative Learning (CSCL). In short, the CSCL is a learning approach that focuses on how the students can learn together with the help of technology.

V. COLLABORATIVE AR: PAST RESEARCH RESULT

A. *Information about Collaborative AR*

Although ongoing AR studies have reached a forty-year milestone, its formal usability [14] and potential [23] in an educational system is still at the primary stage. Most AR studies concern the technological aspect instead of its pedagogical value, especially in collaborative learning. Survey by [24], for example, has shown that out of 161 publications, only 2 focused on collaborative learning. However, a number of recent studies have attended to collaborative AR applications in education. Thus, in this section, we present a review of literature on collaborative AR learning. Included are the applications, participants, methodology and suggestions for future studies. Table I shows the list of selected papers that focus on collaborative AR learning.

TABLE I. LIST OF COLLABORATIVE AR LEARNING RESEARCH

Authors	System	Subjects	Methodology	Topics
[25]	Virtuoso	48 subjects (aged 20-43)	Questionnaire	Art history
[26]	Protein Magic Book	96 subjects	Questionnaire and think aloud protocol	Protein structure
[27]	SMART	54 subjects (aged 7-8)	Video recording, pretest-posttest	Animal and transportation categorization
[28]	Alien Contact!	80 middle and high school students	Observations, interviews, documents	Math, language arts, and literacy skills
[29]	Not mentioned	1st cohort (22 child aged 5-6); 2nd cohort (36 children aged 3-5)	Pre-post tests, observations, interviews, and digital logs of the actions	Animals and the environments

[30]	ARex	12 subjects	Questionnaire, observation and think aloud protocol	Light dispersion and combination
[31]	Not mentioned	36 undergraduate students	Pre-post test, Questionnaire	Physic
[32]	The Table Mystery	6 experts	Observation and interviews	Chemistry, periodic table
[33]	Not mentioned	15 participants	Questionnaire	Flower gardening
[34]	AR Physics	40 undergraduate students	Pre-post test, video taping	Physics

In 2006, Wagner, Schmalstieg, and Billinghurst [25] developed an educational-based collaborative handheld game named Virtuoso for learning the history of art. The aim of this game was to sort through a collection of artworks according to their creation date along with a timeline, in three different conditions: cards, a PC and a PDA. To increase the level of collaboration, the participants were informed that their target was to obtain a high team score rather than individual score. The results concluded that even with three different game conditions, there were no significant differences in the educational outcomes. Interestingly, the players preferred the paper and PDA version because these versions allowed them to collaborate more effectively compared to the PC version. Besides that, they also chose the PDA interface as the most enjoyable among the three [25]. The Virtuoso however, produced low quality audio and a small screen that might interfere with the collaboration process and affect the measurement.

Chen [26] tried to explain the effectiveness of peer learning in an AR-based learning environment to facilitate students in learning chemistry. The study also addressed the cognitive load that students encountered in two conditions: working alone and working with peers. Hence, an AR application called Protein Magic Book (PMB), developed at the Human Interface Technology Laboratory (HIT Lab), was presented as a learning tool. The evaluation was conducted through a questionnaire and think aloud protocol on 96 subjects. 44 students were randomly assigned to a group that required studying the PMB in pairs; another 26 students were assigned to a group that had to study the PMB individually. Another 26 students were assigned to a control group that studied the same lesson without the AR. From the results, the author concluded that students performed better in an AR learning when learning alone compared to the other two groups. In addition, learning a new material with peers has been documented as a high cognitive load. Therefore, designing and developing an effective peer learning approach in an AR-based learning environment should be investigated in future studies.

SMART (System of Augmented Reality for Teaching) is a collaborative AR system specifically designed for teaching 2nd grade-level students about different modes of transportation and types of animals. The settings of this study included a number of racquets that have AR markers, a laptop, software, a web camera and a projector. To foster collaborative learning, a large projected surface was used so the whole class could watch and learn together. They conducted the study with 54 students (aged 7-8) from three local primary schools. In each school, the participants were randomly assigned into two groups: (1) control group which used a traditional teaching and learning method; (2) experimental group which used the SMART system as a learning tool. It is interesting to note that in this study, the SMART has shown positive influences on students' motivation, learning experience and collaboration [27].

In 2009, Dunleavy, Dede, and Mitchell [28] designed Alien Contact!, a mobile AR game developed to support students in a middle and a high school learn math, language arts, and scientific literacy skills. The concept of this game is based on a scenario of alien invasion. The participants were required to work as a team four, carrying four roles: a chemist, a cryptologist, a computer Hacker, and an FBI agent. They had to solve science, math and language problems to determine why the aliens have landed on earth by collaborating and sharing information with their teams. High levels of student engagements were shown across the three case studies [29]. Moreover, the collaborative elements such as role playing and positive interdependence employed in the Alien Contact! and the AR capabilities were suitable. Unfortunately, this investigation was limited by GPS error issues. Students and teachers argued that having GPS error was frustrating, and could have affected the whole experiment.

In 2011, Campos, Pessanha, and Jorge [29] presented a game-based augmented reality to study how this game can support collaborative learning among kindergarten students. This study involved exploring animals and the environments they live in (sea, rivers, land and air) by using AR markers and a wooden board. The authors tested the game by using a combination of quantitative and qualitative approaches with several classes of students in different schools. Two experiments were conducted; the first was with 22 children aged between 5-6 and the second experiment was with 36 children aged between 3-5. Both experiments required students to interact with the system in a collaborative setting using a projector as the display device. Two versions of the game were developed; 1. a version where feedback can be given at any time and 2. a version where feedback is only given at the end of the game. In this study, the game based AR was found to have positive effects, especially when the children were given immediate feedback that boosted the number of interactions and collaborative behaviors among them.

Matcha and Rambli [30] has developed an AR prototype named Augmented Reality Experiment (AReX) that aimed to explore the potential of AR spaces to support collaborative learning. The learning content in this study included the concept of light dispersion and combination. The technology used in ARex was evaluated through questionnaires, observations and think aloud protocol with 12 participants that were grouped into pairs. The results indicated that the AR technology can be used as a medium for collaborative learning. However, the number of respondents was relatively small, thus these findings need to be corroborated with a larger sample. In addition, [30] pointed out that ARex requires improvements because it lacks explanation and consequences related to the experiment.

Physics education with a collaborative AR technique was approached in [31]. This study attempted to investigate how an AR-supported simulation influences collaborative learning. It began by comparing AR learning condition and the traditional face-to-face setting. Therefore, a mobile AR system was developed as a learning tool to simulate an elastic collision (physic phenomenon). This study included two types of sessions: AR-supported and non-AR supported (traditional teaching session). The subjects were randomly assigned to either the AR-supported or the non-AR supported condition. The developed AR system allowed each group of two students to give the values of mass and velocity. The system then visualized the simulation of an elastic collision of two 3D virtual objects (cubes) in their mobile phones. The results of this study indicated that students' collaboration in the AR-supported simulation had exhibited better results in developing skills, self-reported learning and learning interest compared to those in the non-AR-supported session.

A recent study by [32] had involved developing an AR collaborative game for learning the elements of the periodic table, or The Table Mystery, in chemistry lesson. Apart from providing educational experiences to the students, this game also aimed to promote and support collaboration. Working in teams, the students had to collaborate in order to navigate the different levels in the game. Since The Table Mystery was still under development, the authors had conducted trial experiments on the game with experts; teachers and a team from the Science Centre, to ensure content suitability. During the test-gaming session, the experts did not encounter any technical problems and the AR had worked properly. In addition, the educational content in the game was approved to be suitable. However as stated by the experts, there were several limitations that require some modifications in the next version and for future tests.

Implementing collaborative AR learning system with the assistance of interactive agents was also conducted. In a study conducted by [33], they presented an AR learning system that allowed students to experience interactive flower gardening by collaborating with an interactive agent over a real book. The authors created a collaborative environment by assigning problems where students were allowed to interact with the agent in order to accomplish their tasks. To do so, students had to decide on a suitable simulation factor and applied it to an augmented flower. Because the interactive agent coexisted in the real environment, it acted as a problem solving peer support in real time. In order to evaluate the usability and effectiveness of this newly-developed system, a survey was conducted on 15 participants aged 8 to 13. They were required to answer a questionnaire to indicate their satisfaction after finishing the experiment. The results documented high student interests, motivation and engagement in the learning environment. Furthermore, it had also provided them with proper guidelines for problem solving while learning how to collaborate to complete a given task.

Meanwhile, Lin *et al*., [34] has focused on the impact of a mobile collaborative AR simulation system on students' knowledge construction behaviors and learning performances on the topic of elastic collision. Through an experimental design, 40 undergraduates were divided into two groups; i) a group involved with the mobile collaborative AR simulation system and ii) a group assisted by a traditional 2D simulation system. The students' learning performances were assessed through a pre-test and post-test evaluation. The collaborative element applied here was the AR system itself; each of two 3D virtual cubes has to be controlled by one user. Plus, the simulation process would only start after receiving data from both learners. In addition, two open-ended questions related to elastic collision were given to each dyad as a discussion task. This study proved that students in the AR physics group had performed better than those who learned with 2D physics. In fact, the behavior pattern identified from the interaction analysis has indicated that this system can be used as a learning tool to support the knowledge construction processes among dyads.

B. *Integration of Collaborative Learning*

Collaborative learning approaches that have been adopted in creating AR learning environments can be divided into two ways: whether a) collaborative approach was an integral part of the AR system or b) collaborative approach was a learning strategy employed by the investigators. Studies [28][32][33][34] have shown that they have successfully integrate or apply the collaborative learning approach into the AR system. As indicated in [28] that the roles and the positive inter-dependence are integral components of Alien Contact! and are well-matched for the features of AR. While other studies [25][26][27][29][30][31] focusing on the employing the collaborative approach to be use as a learning strategy among students when they use the AR system.

VI. Potential and Challenges of Collaborative AR in Education

A. *Educational Benefits*

From this review, some of the educational benefits of utilizing collaborative AR are presented. With the unique ability to generate objects or virtual information in the real-world environment, the AR provides a combination of real and virtual environments that is unachievable with the use of other technologies. This characteristic is useful when constructing a immersive hybrid learning environment. It can also help improve process skills such as critical thinking, problem solving and communications via collaborative tasks [28]. Additionally, the use of 3D registration of the virtual and real objects in an AR allows users to view the learning content in 3D perspectives. This affordance can help students who have difficulty visualizing complex learning concepts. [26][27][29][30][31] and [33] found that AR can assist students to understand and learn new concepts and phenomenon that cannot be viewed in the real world.

Freitas and Campos [27] and Campos, Pessanha, and Jorge [29] pointed out that by learning through play, the uses AR in education have actually reduced the gap between children and knowledge. As [27] argued; "poor students are, in general, more prone to physical activity, and playing with the physical racquets might positively influence their learning behavior". In fact, with its simulation of virtual objects in real time, the AR help students to visualize and learn new concepts [30], achieve significantly higher learning comprehension [31][33] and achieve higher levels of learner satisfaction [34] than those who learn via the traditional systems. The emergence and widespread use of mobile devices such as smartphones and tablets furthermore, have opened new opportunities for AR integration. As such, co-located learners may gain knowledge by discovering the outside environment and interact with each other, through the AR's guidance [28][31].

The AR can also catch and hold users' attention [30] and increase students' level of engagement [28] with the course content, which leads to better academic achievements. In fact, the AR learning environments have positively impacted students' motivation [28][29], allowing them to gain concise knowledge of the subject matter. Students have also shown high levels of motivation [28][29] and interest [30] while performing tasks and studying, particularly when they were allowed to go outside for physical exploration [28]. These children were clearly motivated because they never gave up on the game until they have found the answer. This behaviour implied that their motivations were fuelled by the integrated AR technology in their learning environment.

Additionally, students were allowed to control the 3D virtual objects with peers or teachers to promote better collaboration. Researchers agreed that the AR supports collaborative learning on digital information and each other in the same space. [26] and [31] have claimed that the AR technology plays an important role in the effectiveness of collaborative learning. Several students reported that active exchange of knowledge during collaborative learning sessions have encouraged them to achieve higher levels of learning efficiency, engagement and enjoyment. These factors are essential in producing better understanding of the lesson. In addition, students who collaborated in an AR session may perceive higher levels of learning skills and interest compared to those without. The AR can also support many types of communication cues [30], making learning contents easier [26]. In the AR learning environment developed by [29], immediate feedback played an important role; it stimulated better collaborative behaviours and smoother interactions among children. Thus, students' comprehensions are enhanced because the learner-instructor and learner–learner interactions are supported by AR which maximized the transfer of learning [35]. Indeed, researchers believe that the AR has shown great capacity to be integrated into the teaching and learning environment.

B. *The Challenges*

Although collaborative AR learning systems have significantly affected the teaching and learning process, some negative issues and challenges remain to be solved. The most frequently reported downside of the AR during the learning process is cognitive overload as experienced by students [26][28]. In many studies, researchers conclude that when participants encounter a large amount of information, the complexity of the task and their unfamiliarity of the technology (participants might never have experienced an AR technology) may cause cognitive overload. Therefore, designing proper scaffolding mechanisms or instructional prompts when using AR is necessary to help maximize students' learning capabilities and minimize cognitive loading problems.

Another challenge as reported in the review is the issue of hardware and software failures. As reported by [28], GPS error was experienced within the AR. Interviews with teachers and students showed that GPS error was the most significant drawbacks when using the AR. This problematic issue had caused major disappointments. However, as information technology continues to evolve, the issues of GPS error and device stability may be solved soon. Implementation is another limiting aspect found during this review. The interviews clearly showed that teachers felt overwhelmed with the high management requirement of implementing the AR [28]. They stressed on the crucial need for adequate support of two to three people to ensure proper implementation without technical problems. Additionally, participants in [25] have reported that learning through the AR incorporated mobile phones or PDA limits them to small screens. These participants found difficulty in collaborating with other participants and to explore and view the 3D virtual contents.

VII. Conclusion

It is clear that there are benefits and challenges in incorporating collaborative AR into educational settings. However, we believe that the AR's potential may be further expanded because it is increasingly recognized, especially among researchers in the field of education. By utilizing proper instructional strategies, AR may provide students with numerous benefits which may lead to effective learning experiences. This review may assist us in understanding the role of AR in collaborative learning. The integration has shown positive educational effects which have resulted in a higher level of motivation, learning performance, engagement and collaboration among students. As information technology evolves, the AR opens up new opportunities to create educational experiences that are more engaging and interactive. Further investigations however, are required to overcome the shortcoming and enhance the current AR technology designed for the educational system.

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