

## Influences of AR-supported Simulation on Learning Effectiveness in Face-to-face Collaborative Learning for Physics

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**Abstract**—Augmented Reality (AR), using a mixture of the virtual and physical world, has been recognized as a promising environment for improving the quality of collaboration in educational domains. To identify how an AR-supported simulation affects collaborative learning, this study compared collaborative learning effectiveness between the conditions of AR-supported and traditional face-to-face collaborative learning for Physics. The findings revealed that collaborative use of the AR-supported simulation resulted in higher levels of perceived skill development, self-reported learning and learning interest. The individual learning achievement was also strengthened with the use of AR-supported simulation in collaboration. This study provides empirical evidence for supporting the potential value of AR technology in collaborative learning practices and has implications for research on learning effectiveness evaluation in CSCL.

**Keywords**—CSCL; augmented reality; collaborative learning; learning effectiveness

### I. INTRODUCTION

The development of computing technologies contributes to the expansion of computer-supported collaborative learning (CSCL) activities. Augmented Reality (AR) technology, which allows computer-generated virtual objects to be overlaid onto the physical world, demonstrates great potential for constructing more engaging CSCL environments [6].

AR technology possesses multiple characteristics for promoting the efficacy of face-to-face collaborative learning. In the context of collaborative AR, multiple users can simultaneously access a shared space and manipulate the virtual objects to engage in collaboration. Also, AR technology entails great capacity for implementing interactive visualization. It allows collaborators to experiment with simulations and reflect on abstract concepts and principles in science subjects. Featured with a

combination of attributes of the virtual reality and the real world, AR technology does not only enable delivery of enriched learning experiences, but also makes it possible for collaborators to step back from the scenario and analyze the situation reflectively.

In order to deepen the understanding of the impacts of AR technology on collaborative learning, researchers have started assessing AR applications in educational domains. They found that the integration of AR technology with collaboration reveals great promises for enhancing learning effectiveness [2, 3].

The primary purpose of learning is to strengthen initiative and competence, and the learning outcome is an essential issue for the evaluation of learning effectiveness. The way of conceptualizing learning outcomes is important for the understanding of the learning effectiveness of collaborative learning [7]. It is suggested that both objective learning achievement and perceived learning effectiveness should be addressed to evaluate the effectiveness of collaboration.

In collaborative learning contexts, the quality of group performance is assessed to facilitate the understanding of group functioning. Besides evaluating objective performance at the group level, individual learning achievement is an important indicator to measure the effectiveness of collaborative learning. Perceived learning effectiveness, evaluated by individuals' perceptions towards the learning activity, is a subjective measurement employed in the research of evaluation of collaborative learning effectiveness. Previous work indicated that direct feedback of learning effectiveness from students is useful for obtaining insightful thoughts on the efficacy of collaborative learning [4].

The aim of this research is to explore the influences of an AR-supported simulation on the effectiveness of face-to-face collaborative learning for Physics. We have designed a mobile AR system for implementing elastic collision, which is a typical phenomenon in the education of dynamics in

Physics. The findings will support the worth of AR technology in collaborative learning and enrich the research on learning effectiveness evaluation in CSCL.

## II. METHODS

### A. Participants

36 undergraduate students from the National University of Singapore participated in the study. The criterion for being a participant was that he/she must have taken Physics as a subject in Secondary School but not taken it in Junior College/Polytechnic. This ensured that the participants had basic knowledge of motion and energy, but did not know about linear momentum and elastic collision. The sample included 16 males and 20 females, whose age ranged from 20 to 25 years old ( $M=21.31$ ,  $SD=1.33$ ).

### B. Procedure

All 36 participants were first asked to read a set of notes, which was extracted from notes prepared by the physics department of a local Junior College, on elastic collision for 15 minutes independently. They were divided into 18 two-member groups, and then were randomly assigned to either the non-AR-supported (with instructional material) or the AR-supported (with AR support) condition. Each group was asked to discuss the questions as follows: “Under the context that object B is stationary and object A moves towards object B, how many kinds of subsequent motions can happen after the elastic collision between them? What are the initial conditions required for those subsequent motions to occur?” Since the questions had standard answers, the group performance could be objectively evaluated. For the groups assigned to the AR-supported condition, they were instructed in the way of manipulating the AR system before the discussion. For the groups in the non-AR-supported condition, they were to discuss the questions without the AR system right after the individual reading. In both conditions, once the two students in a group had reached an agreement, they would submit a discussion summary. To assess individual learning achievement, post-test questions based on the knowledge of elastic collision were given. Finally, the participant had to fill in a questionnaire that was used to capture his/her perception on the learning experience in collaboration.

### C. Measurements

The collaborative learning effectiveness was assessed by two dimensions: perceived learning effectiveness and learning achievement. The scales for measuring perceived learning effectiveness were adapted from Alavi [5] and modified for this research context, including multi-item individual learning and group learning evaluation scales. Individual learning scales consisted of perceived skill development, self-reported learning and learning interest, while group learning evaluation scales were mainly about the evaluation of collaboration. Each item was assessed using a five-point Likert-type scale. The reliability of perceived skill development, self-reported learning, learning interest and group learning evaluation were 0.768, 0.730, 0.707 and

0.898 respectively. The score of the group discussion summary was used to evaluate the group performance, while the score of the individual test after the discussion was applied to assess the individual learning achievement.

### D. The system

We developed a mobile AR system to simulate elastic collision for assisting face-to-face collaborative learning (See Figure 1, top left). The software prototype has been implemented on an HTC Nexus One phone running Android OS 2.2 with a supporting server program on a PC. The computationally expensive algorithmic computations for marker detection and physics simulation were designed to be carried out on a server, and results were sent back and visualized on the mobile phone.

The system enables both users to visualize two 3D virtual cubes on a marker as well as simulate elastic collision in a virtual shared space with their mobile phones. Each virtual cube is assigned to a user and its mass and initial velocity can be controlled by that user. Users can input the numbers using the interface provided to simulate elastic collision (Figure 1, top right). After both users have finished editing the initial conditions, they can press ok to start the simulation. The whole collision process is visualized with real-time numerical data of mass, velocity, momentum and kinetic energy of the two objects displayed on the left side of the screen. During the whole discussion process, two users are free to choose the appropriate period to use the system and are allowed to run simulations as many times as they may need to derive the answer to the question.



Figure 1. AR-supported collaborative physics learning

## III. RESULTS

### A. Perceived learning effectiveness

The analysis indicated that the participants with the AR-supported simulation gave significantly higher ratings in perceived skill development than those in the non-AR-supported groups.

For self-reported learning and learning interest, there were also significant differences between the AR-supported groups and the non-AR-supported groups.

Participants made more favorable group learning evaluations than other individual learning scales in both conditions. It was higher for the AR-supported groups than the non-AR-supported groups, but the difference was not significant (See Table I).

TABLE I. MEAN (SD) RESULTS FOR PERCEIVED LEARNING EFFECTIVENESS

Dependent variable	AR mean (SD)	Non-AR mean (SD)	t-value
Perceived skill development	3.87(0.57)	3.40(0.59)	2.38*
Self-reported learning	3.83(0.37)	3.39(0.77)	2.20*
Learning interests	2.98(0.58)	2.36(0.73)	2.82**
Group learning evaluation	4.06(0.76)	3.89(0.41)	0.80

NOTE: \*\* $p < 0.01$ , \* $p < 0.05$

### B. Learning performance

Participants in the AR-supported groups performed better on the discussion task than those in the non-AR-supported groups, but no statistically significant difference was found. Individual post-test results showed that participants in the AR-supported groups got significantly higher scores than those in the non-AR-supported groups (See Table II).

TABLE II. MEAN (SD) RESULTS FOR LEARNING PERFORMANCE

Dependent variable	AR mean (SD)	Non-AR mean (SD)	t-value
Group performance	7.00(1.41)	6.22(1.86)	1.00
Individual achievement	7.03(2.53)	5.00(2.36)	2.50*

NOTE: \* $p < 0.05$

## IV. DISCUSSION

In this study, we investigated the impact of an AR-supported simulation on the effectiveness of face-to-face collaborative learning for Physics. The results demonstrated the facilitation effects of AR technology on collaborative learning effectiveness.

The collaborators with the AR-supported simulation perceived higher levels of learning skill development, self-reported learning and learning interest after the discussion compared with those without simulation support. The findings revealed that the AR-supported simulation met the requirements for performing effective instruction, and fostering the development of learning initiative and competence [8].

The average rating of the group learning evaluation was the highest among the perceived learning effectiveness scales. The participants reported that collaborative learning led to an active exchange of knowledge, higher learning efficiency, and increased engagement and fun, which were helpful for generating better understanding of concepts and solutions. The use of AR-supported simulation resulted in an increase in group learning evaluation but it was not statistically significant. Since collaborative learning was preferred by students, integrating AR technology with collaborative learning could possibly inspire students' learning interests.

The difference in group learning performance between the AR-supported and the non-AR-supported groups was not

significant, while the use of AR positively affected individual learning achievement. This implied that the AR-supported simulation in collaboration was more likely to serve as a kind of learning resource rather than a collaboration facilitator. Hence, collaborative use of the AR-supported simulation has more obvious effects on individual learning achievement than on group performance.

## V. CONCLUSION AND FUTURE WORK

AR interfaces are perceived as the "next generation" pedagogical media to advance learning quality [1]. In this paper, we validated the potential role of AR technology in enhancing collaborative learning effectiveness for Physics. Perceived skill development, self-reported learning and learning interest were strengthened in the AR-supported collaboration. Also, it promoted individual learning achievement.

This study contributes to CSCL research by empirically verifying the positive influences of AR technology on collaborative learning and provides insight into the approach of assessing collaborative learning effectiveness. Future research is needed to explore the mechanism underlying the effectiveness of AR-supported collaborative learning.

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