An investigation of Students' Sequential Learning Behavioral Patterns in Mobile CSCL Learning Systems

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***Abstract*—This paper attempts to explore students' collaborative learning behavior patterns in different simulation systems. Two mobile CSCL learning environments (Augmented Reality simulation and Traditional simulation) for helping university students to acquire physics knowledge were designed. A total of 40 students, grouped into twenty pairs, were randomly assigned to the two learning environments for conducting an inquiry task. Their collaborative learning behaviors were recorded and analyzed by quantitative content analysis and lag sequential analysis. The results indicated that the students' collaborative inquiry learning was supported in both environments. Particularly, the students using the AR-simulation showed a more cohesive collaborative inquiry learning behavior pattern. This study provides a new perspective for educators or system designers to deeply observe students' learning behaviors in a CSCL environment by using sequential analysis. Moreover, the AR-simulation system might be a suitable learning environment for enhancing students' collaborative inquiry learning. In addition, suggestions for designing a simulated learning environment are proposed.**

Keywords-Mobile CSCL, behavior pattern, collaborative inquiry learning, simulation, augmented reality.

I. INTRODUCTION

Inquiry learning is conceived as an effect and efficient learning activity in which students are placed in the position of scientist investigating knowledge of the world. Students could arrange all the steps of scientific investigation on their own. Meanwhile, collaboration between students is also effective for enhancing inquiry learning. The combination of inquiry learning and collaborative learning (i.e. collaborative inquiry learning) leads a very powerful learning environment [1].

With the merits of computers and the Internet, computer-supported collaborative learning (CSCL) environments contribute more possibilities for enhancing students' learning. Learning technology, such as computer simulation and mobile technology, plays an important role on supporting students as they work in collaborative inquiry learning. Derived from the advantages of CSCL and inquiry learning, collaborative inquiry learning is considered as a promising strategy for fostering students' learning of science [2]. Students can acquire scientific knowledge and cultivate their understanding of the nature of science through collaborative inquiry learning.

Computer simulations have been widely used for supporting students' collaborative inquiry learning in previous studies [2]. Some simulation learning environments, such as Co-Lab and Model-it, have been employed to facilitate the processes of inquiry [3]. In these environments, students can build their own models, generate and test hypotheses, and observe the results iteratively via simulation [1]. Recently, Augmented Reality (AR), a real-time technology that blends virtual objects or environments with the real world, has revealed great potential for enriching the simulations with more authentic learning experiences [4, 5].

Moreover, computer-supported learning environments have evolved with the advances in computing technology, such as mobile technology. With the development of mobile technology, the mobility of handheld devices allows students to have more physical contact with peers, and consequently enhances their coordination and interactivity in CSCL activities [6]. AR also brings great possibilities for supporting face-to-face collaborative learning [5]. In other words, utilizing mobile and AR technologies might foster

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the collaborative inquiry learning activity. In previous studies, computer simulations have already been recognized as an effective way of promoting students' collaborative inquiry learning [2]. However, the effectiveness of simulation systems supported by mobile AR technology in terms of students' learning is still unclear.

The most commonly adopted method for examining the surface effectiveness of a simulation system for learning is quantitative, that is comparing the students' learning achievements before and after using the system. On the other hand, some qualitative methods, such as content analysis, have also been employed to obtain more detail and deeper insights. However, researchers [7, 8] have indicated that the results of content analysis alone still lack the detail required to understand the behavior patterns and sequential progression of the entire discussion. Lag sequential analysis is used to investigate the significance of the sequential correlation between each discussion behavior [9]. This method of examining users' online behavior patterns has been widely used by researchers [8, 10]. Through inferring their behavior patterns, we can understand how students experience the learning system. These experiences could then provide educators or system designers with an important reference for improving their learning systems [11].

Therefore, the aim of this research is to explore the students' collaborative inquiry learning behavioral patterns in two CSCL environments (AR simulation and traditional simulation). The findings will help us to understand the learning behavioral patterns and determine the effectiveness or limitations of such simulation learning environments.

II. METHOD

A. Participants

A total of 40 undergraduate students were recruited for the study. The participants were all volunteers and were selected according to the following criterion: he/she had taken physics classes before but had not learned the related lessons about elastic collision. There were 16 males and 24 females (aged 21 to 27, M=21.98, SD=1.36) in total. Additionally, none of them had any prior experience of using the learning system adopted in this study.

B. Procedures

Due to their lack of relevant understanding of the learning topic, the students were asked to read a set of instructions regarding the basic concepts of elastic collision for 15 minutes individually. Then, they were randomly grouped into pairs and also randomly assigned to either one of the two experimental groups: an AR-supported Simulation system (ARS) and a Traditional Simulation system (TS). Next, the participants were instructed in how to use the systems. Finally, each pair was asked to conduct a scientific inquiry task with two open-ended questions related to elastic collision as follows by using the simulation system:

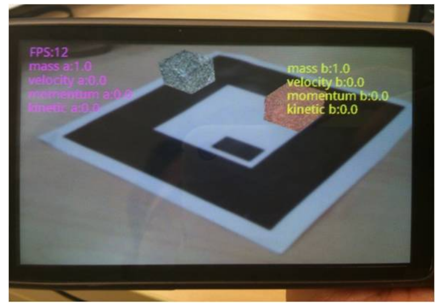

Figure 1. Screenshot of the AR-Simulation

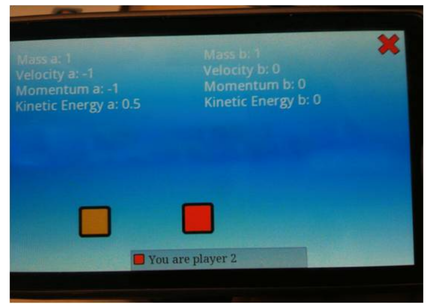

Figure 2. Screenshot of the Traditional Simulation

- Under the context that the object B is stationary and the object A moves towards B, how many kinds of subsequent motions can happen after the elastic collision? How does the relationship between the masses of two objects influence the subsequent motions of the two objects after the collision?
- How do you explain the change of motions of the two objects after elastic collision?

The collaboration inquiry learning task was regarded as finished when each pair reached agreement on the answers of the questions and submitted a discussion summary.

C. Learning Environmonets

The present study was undertaken to explore the students' collaborative inquiry learning behavior patterns in different learning environments (i.e. ARS and TS). The systems were developed to help the students acquire the knowledge of elastic collision by way of collaborative learning. The learning environments were implemented on mobile devices (i.e. HTC Nexus One running Android OS 2.2) with a supporting server program on a PC. With the mobility, students would not be fixed in front of desktop computers. They could discuss and arrange their inquiry steps at anyplace and in anytime according to their preferences. The physical interactions and communications between students would be fostered as well.

In the ARS environment, the system could detect the marker and blend a 3D physics simulation on it. Each student had his/her own mobile device, and could visualize two 3D virtual cubes on a marker and simulate the experiment of elastic collision in a shared virtual space with the mobile phone. In other words, each cube was controlled by one student. Each student could modify the parameters and see the process of elastic collision on his/her own mobile device. The mass and initial velocity of the cube that he/she controlled could be set through the input surface. The simulation process only started after receiving the data from both students. Real-time numerical data of the velocity, momentum and kinetic energy of the two objects in the collision were displayed on the two sides of the screen, as shown in Figure 1.

The settings of the TS environment were almost the same as those of the ARS environment, but a simple simulation environment was provided instead. As shown in Figure 2, each student also had his/her own mobile device.

He/she could control his/her cube and change the mass and initial velocity of the cube in the same way as their counterparts using the ARS system. The real-time numerical data of the velocity, momentum and kinetic energy of the two objects in the collision were displayed on his/her screens as well.

During the discussion process, the two students in each pair were free to choose the appropriate period to use the system, and were allowed to run simulations as many times as they needed to fulfill the task.

D. Data collection and analysis

All the students' collaborative learning processes were recorded by video and transcribed verbatim for analysis. Then the transcripts of discussion were segmented into utterances. An utterance is defined as representing one student's single learning behavior.

In order to explore the patterns of the students' collaborative inquiry learning behaviors, both quantitative content analysis and sequential analysis were employed in this study.

First, the framework proposed by Gijlers and de Jong [12] was adopted as a coding scheme for content analysis. According to the coding scheme, the students' potential behavior of collaborative inquiry learning could be categorized as five categories: Orientation (O), Hypothesis (H), Experiment (E), Interpretation (I), and Conclusion (C); the definition of each category is shown in Table 1. The utterances extracted from the transcripts were coded into five categories following the coding scheme. The results of the content analysis then became the input to the follow-up sequential analysis.

As sequential analysis requires coding in chronological order, the utterances of behavior were thus coded based on their temporal order. For example, the students first tried to identify the requests of the inquiry task (O). Then they generated a hypothesis (H) and tested it with the simulation system (E). This series of behaviors was thus coded as 'OHE.' After each group of students' behaviors were coded based on careful analysis of the transcripts, 20 sets of code strings with 1,108 behavioral codes were obtained for the sequential analysis.

TABLE I. CODING SCHEME OF COLLABORATIVE INQUIRY LEARNING

Codes	Students' behaviors
O	Identifying the variables
H	Specifying the relation between variables and generating hypotheses
E	Using simulation to implement experiments and collect data
I	Dealing with the interpretation of data and results
C	Reflecting on experiments or making conclusions

TABLE II. ADJUSTED RESIDUAL TABLE OF STUDENTS USING ARS.

	O	H	E	I	C
O	0.29	3.18*	3.47*	-2.30	-2.29
H	2.07*	2.34*	5.27*	-3.58	-2.60
E	1.27	-2.17	2.94*	0.86	-3.73
I	-2.30	-0.46	-3.65	2.01*	3.41*
C	-1.85	-1.05	-3.21	0.91	2.27*

TABLE III. ADJUSTED RESIDUAL TABLE OF STUDENTS USING TS.

	O	H	E	I	C
O	3.59*	0.86	2.19*	-2.02	-1.85
H	1.30	3.16*	5.72*	-3.54	-2.35
E	0.48	-0.20	1.21	1.18	-2.99
I	-2.40	-1.17	-3.53	3.42*	1.30
C	-0.88	-1.61	-1.85	-1.41	4.32*

In order to investigate the reliability of the behavioral codes, we selected 10% of the data and trained another coder to work independently with the coding system. The reliability coefficient between the two coders reached 0.83 (Cohen's kappa).

III. RESULTS AND DISCUSSION

By using sequential analysis [9], the frequency of each behavior category immediately following another was counted, and the reached significance of correlations between each sequence was calculated. In Table 2 and Table 3, the adjusted residuals among the students' learning behaviors in the two learning environments are presented.

The rows indicate starting-behaviors while the columns indicate follow-up behaviors. Z-scores that are greater than +1.96 indicate that the behavioral continuity from a certain row to a certain column has reached statistical significance ($P < 0.05$). For example, in Table 2, the value of the sequence O->H is 3.18 and reaches the level of significance.

The significant sequences are transformed into Figure 2 and Figure 3, representing the 'ARS group' and 'TS group' respectively. These two diagrams allow us to infer the students' sequential behavioral patterns in the two groups. In

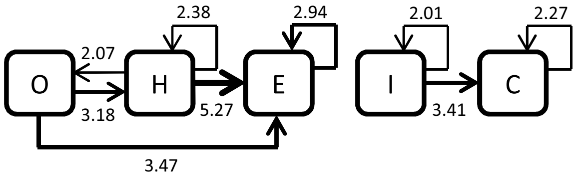

Figure 3. Sequential pattern of behaviors in the ARS

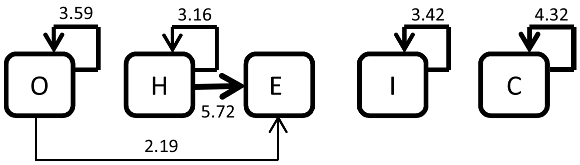

Figure 4. Sequential pattern of behaviors in the TS

other words, we can understand the students' collaborative inquiry learning behaviors in the two learning environments from the diagrams. The arrow indicates the direction of transfer for each sequence, and the thickness represents the level of significance.

Figure 3 indicates that the students using the AR-simulation system demonstrated the behavioral sequences O<->H, H->E, I->V, O<->E, E->E, H->H, I->I, and V->V, where the '->' indicates a unidirectional sequence and '<->' indicates bi-directionality. The sequences O (Orientation) <->H (Hypothesis) and H->E (Experiment) indicate that by using AR-simulation, the students could iteratively conduct the processes of analyzing tasks and generating hypotheses. Then, the hypotheses would be tested using ARS. The collaborative inquiry behavior pattern H -> H is a significantly looped which implies that the ARS environment stimulates students to discuss and elaborate their hypotheses. The students repeated the experiments by using AR-simulation (E->E). O->E reveals that some students might use the AR-simulation directly after orientation.

Furthermore, the sequences I->I (Interpretation), I->C (Conclusion), and C->C are significant. They reveal that the students could iteratively discuss the results of the experiments with each other by using the AR-simulation (I->I). Consequently, their interpretations would be the references to make conclusions (I->C), and they could refine the conclusion with continuing negotiations or elaborations (C->C).

Figure 4 indicates that students using the TS system demonstrated the behavioral sequences O->O, O->E, H->E, H->H, I->I, and C->C. The sequence O->O indicates that when the students attempted to propose questions, they showed a tendency to reanalyze their inquiry tasks. The sequences H->H and H->E indicate that the students could discuss, generate, and then test their hypotheses by using the TS system. The sequence O->E shows that they would conduct their experiments directly after the process of searching for orientations. In addition, in the TS environment, the students would be involved in interpreting and concluding their findings collaboratively (I->I and C->C).

From the learning behavior patterns revealed in this study, both environments could improve students' collaborations to generate hypotheses (H->H), test their hypotheses with simulation functions (H->E), interpret results (I->I) and conclude their findings (C->C). Previous studies have indicated that simulation environments could support students' scientific inquiry learning processes, such as interpreting results, and improving knowledge integration [2, 3]. Moreover, the pattern O->E also appeared in both systems. Researchers have indicated that students are interested in using computer simulations [2]. Therefore, they might tend to use the simulations directly without making appropriate hypotheses. In sum, both learning environments are able to attract students and play a role in supporting their collaborative inquiry learning.

Particularly, three more behavior sequences are found only in ARS. First, students' hypothesis-generation behaviors were based on their task analyses (O->H). Second, if they met some problems during the hypothesis generating process, they would go back to reanalyze the task and regenerate hypotheses (H->O). Third, they would make conclusions after interpreting the results data (I->C). These findings reveal that the learning behavior pattern of using ARS is much more closely fitted to the ideal collaborative inquiry processes suggested by Bell et al. [2]. Therefore, the AR system would help students to explore the task following the inquiry processes. These differences imply that the AR-simulation system might be more suitable for students to conduct scientific inquiry learning.

A limitation is also found in the environments. The sequence E->I is not significant in either pattern. Theoretically, the students' next step of conducting experiments should be to interpret the results. However, the present finding shows that these students' sequential correlations between 'Experiments' and 'Interpretations' are not significant. When students use the simulation systems, the results of experiments will be obtained immediately and be 100% correct due to the powerful computing functions. Bell et al. [2] have indicated that students who use computer tools (i.e. simulation) for conducting experiments tend to focus on higher processes of inquiry, such as interpretation and conclusion. In this study, the two significant sequences (I->I and C->C) which represent higher inquiry learning behavior in both systems might support their suggestions. Actually, we could find that the sequence E-> I occurred quite often in the transcripts, but the frequencies are not significant when using lag sequential analysis. Moreover, Chen [13] has indicated that simulations might convey an oversimplified view of scientific inquiry to students. The finding in the present study might also reflect this possibility.

IV. CONCLUSION

In this study, we applied sequential analysis to investigate the behavioral patterns revealed in the two different simulation environments (the AR-simulation system and the traditional simulation system) for helping students to acquire knowledge of elastic collision. The findings showed that the functions in both simulation environments support students' collaborative inquiry learning. Students' collaborations were fostered by using the computer-supported simulation environments. Previous study has indicated that mobile CSCL environments could be an effective way to support collaborative learning activities, such as coordination, communication, organization of materials, negotiation, and interactivity [6]. In particular, those students using the AR-simulation system demonstrated cohesive inquiry patterns. Accordingly, the AR-simulation system might be a sufficiently effective environment for conducting collaborative inquiry learning activities.

The AR simulation environment has been identified as an effective medium for enhancing the effectiveness of face-to-face collaborative learning in previous studies. We recommend that this environment be implemented in different learning domains. For cultivating students' scientific inquiry ability, the simulation-based learning environment should include some authentic features of conducting experiments, such as random errors.

Finally, by using lag sequential analysis, we could deeply understand the users' learning patterns in the systems [11]. These patterns might provide a way for designers to evaluate the systems. However, the sample size is quite small in this study. To get more validate evidence to prove the effectiveness of AR simulation on students' collaborative learning, exploring more participants' behavior patterns would be recommended.

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