The Analysis of Collaborative Science Learning with Simulations Through Dual Eye-Tracking Techniques

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Abstract. Collaborative problem solving is a core ability that has been highly valued in recent years. Collaborative problem solving activities allow learners develop collaboration skills. In science education, collaborative learning with simulations enables learners to manipulate a science problem to explore scientific concepts. However, the collaboration during such a learning context is a complicated process and researchers face difficulties in understanding learners' mental effort in using the simulations. The use of dual eye-tracking techniques is helpful to uncover learners' visual attention, and thus to better analyze student collaboration in activities. In this paper, the research focus on learners' difficulties when they learn together with the simulation in different places. The results show that the techniques are helpful to identify the subtle interaction problem including the problem of lacking coordination, the process misunderstanding problem, and misunderstanding in partners' attention. Educators may need to address these problems when simulations are applied to support remote collaborative science learning.

Keywords: Eye-tracking · Collaboration · Science learning

1 Introduction

In recent years, collaborative problem solving (CPS) is one of the core competencies [1]. Therefore, collaborative problem solving activities are frequently applied to help students develop such a competency as they learn to coordinate with the partners to solve problems together. In the past, researchers applied questionnaires or survey to understand collaboration quality during collaborative learning. However, it is suggested that such subjective approach often can not reflect the actual collaboration and mental efforts during collaborative learning [2].

H. Nakanishi et al. (Eds.): CRIWG+CollabTech 2019, LNCS 11677, pp. 36–44, 2019.
https://doi.org/10.1007/978-3-030-28011-6_3

To better capture learners' mental effort, many experts applied eye-tracking analysis technique to analyze students' visual attentions to understand the students' problem solving process [3, 4]. These studies mostly focused on the individual problems solving process, not on the collaboration process. How two individuals' attentions coordinate to solve a problem is not clearly depicted. To conquer such a limitation, dual eye-tracking techniques which collect and analyze two individuals' gaze movements were applied to uncover how two students learn together [5]. The literature has demonstrated the usage of such techniques for the research of collaborative learning.

The present study thus attempts to understand the collaboration process through dual eye-tracking techniques when students at different places learn science together with computer simulations. Collaborative learning with simulations enables learners to manipulate a science problem to explore scientific concepts. It is hoped that the dual eye-tracking techniques can uncover the limitations of the computer simulation in supporting collaborative problem solving. Although eye-tracking techniques are not a completely novel research method [6–8], this study contributed to understand the application of dual eye-tracking techniques in understanding the use and design of computer simulation in supporting science learning.

2 Methods

This study recruited students from a national university in Taiwan. Only students who had normal vision or normal vision after correction and who never participated in similar experiments are included in this study. This study selected two pairs of students as the focus group for detail case study. The two participants of each pair did not know each other before the experiment and they sit in different rooms and talk with the mobile phone system. Such an arrangement simulates the learning situation when students do not co-present in a classroom but learn in different places.

The simulation used in this study is "how much rain" (Fig. 1) that simulates how much rain will fall on to a character who run in different speed. The simulation displays both of the animation and the amount of the rain falling onto the character in three charts.

With the simulation, the student pairs needed to understand whether the character needs to run to avoid getting wetter. This simulation allows students to manipulate the running speed and rainfall density. The students could check the top, side and the total rain falling on the character.

In this study, we defined seven area of interest (AOI) for the analysis of gaze movement (Fig. 1), including the problem description area (AOI1), the simulation control area (AOI2), the simulation animation area (AOI3), the top rain chart displaying the rain falling to the head (AOI4), the side rain chart displaying the rain falling to the character from the side (AOI5), the overall rainfall chart (AOI6) and learning material area (AOI7).

The participants operate the simulation on an individual basis. In other words, the simulations operated by the two students of the student pairs were not synchronized. One pair member's operations on his/her simulation did not interfere with each other. In this scientific learning activity, the two partners must coordinate closely to solve the

Fig. 1. The “how much rain” simulation.

scientific problems. This experiment was 20 min. After the activity, the participants answer a teamwork quality (TWQ) questionnaire [9] to understand their perception about the collaboration.

This study applied the Tobii Eye Tracker 4C at 90 Hz to collect students gaze movement. The Real-time Fixation Identification and Analysis Module (RFIAM) [10] was used to collect the gaze movement. Several AOIs (Area of Interest) regions were defined according to the different components of the simulation (Fig. 1). When student gaze at an AOI, the eye-tracking system will detect such a fixation and recorded the start time and end time of the fixation and the AOI area. This study applied the cross-recurrence plot (CRP) function in MATLAB [11, 12] to analyze the students’ joint attention. The CRP analysis, students’ discourse and their feedback to the TWQ questionnaire was analyzed together to better understand the collaboration process.

3 Results and Discussion

Figure 2 displays the CRP of a pair of this study. The x-axis and y-axis of the matrix represent the activity time of different students. If student A gazed an AOI at time x and student B also gazed the same AOI at time y, then the cell (x, y) at the CRP will be marked. Therefore, the diagonal line represents that the two students observed the same AOI at the same time. This study firstly integrated students’ fixation records with their screen videos to better present students’ visual attention and their screen behaviors. The videos were then analyzed with students’ discourse data. As shown in Fig. 2, Block B shows the two students demonstrated noticeable joint attention. From the discourse B1–B7 (Table 1) we observed that the two are coordinating on the manipulation of the simulation, and thus they both closely watched the AOI2. Therefore, they demonstrated high level of visual joint attention from the intensive marked area around Block B.

However, triangulating the CRP with discourse data (as shown in Table 1) also found that the two experimenters were not aware of the other party's operation. More specifically, while one person was waiting for the other person to operate the simulation, the other person had thought he already completed the simulation (see the discourse A1–A6). We observed that STUDENT A is still watching AOI2, while STUDENT B has visually moved to AOI6 in the chart area. Such results suggest that student will encounter the process misunderstanding problem when they use simulations individually to collaborate to learn. From the difference between Block A and Block B, we found that the CRP can reflect how two individuals pay attention to the simulation and work together.

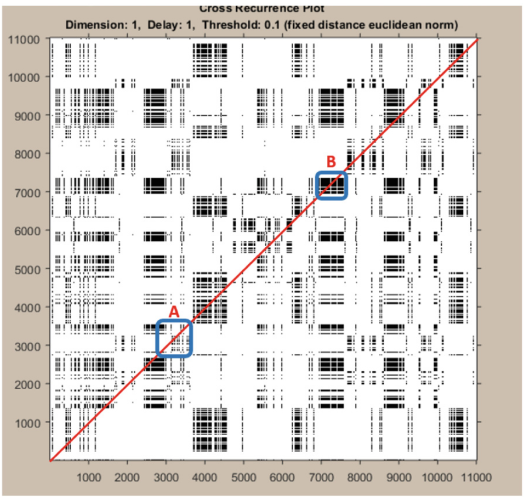


Fig. 2. Introduction to the Cross-Recurrence Plot cooperation status of the pair A.

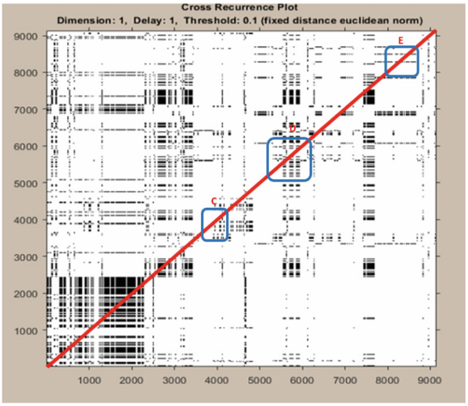
In another case, as shown in Fig. 3 and Table 2, it is observed that there is a problem in the communication between the two people at the beginning (C1–C3). More specifically, STUDENT A suggested to directly discuss the answer of the question and terminate the activity (C2). This is because STUDENT A has already completed the simulation while STUDENT B was still waiting for STUDENT A to discuss how to manipulate the simulation. From discourse C3, we could find that STUDENT B doesn't observe any chart area (AOI4, AOI5, AOI6), while STUDENT A has moved to the chart in AOI5. Such an instance reflects that students encounter the problem of lacking coordination. Such a problem occurred again from D1 to D4. More specifically, when STUDENT A has already completed simulation and was watching the chart of AOI6, STUDENT B was still waiting for STUDENT A to discuss about the variable in the AOI2.

Table 1. Partial dialogue during the experiment and AOI conversion of the pair A.

Number	Timeline (min)	STUDENT A	STUDENT B	AOI_ STUDENT A	AOI_ STUDENT B
A1	02:27		If he run faster and he speed is 3, he gets wet	AOI2→AOI3→AOI2→AOI3	AOI2→AOI6→AOI3→AOI6
A2	02:32		When he arrived at place, he wet value is 202	AOI3→AOI6→AOI2→AOI6	AOI6
A3	02:42	Are you setting 3 now?		AOI6	AOI2
A4	02:45		Yes, it is V = 3 and the density is 4	AOI6→AOI3→AOI2	AOI2
A5	02:48	Is the density 4?		AOI2	AOI5→AOI4→ AOI5→AOI3→AOI4
A6	02:50		Yes°	AOI2→AOI5→AOI2	AOI2
⋮					
B1	05:46	Then I have tested it a few times, I measured…Is setting of rain density high?		AOI2	AOI5→AOI1→AOI2
B2	05:55		Ok, I set the rain density setting to high	AOI2	AOI2
B3	06:02		Then I set the slowest one in running	AOI2→AOI1→AOI2	AOI2
B4	06:08	High density. Which the fastest or the slowest in your setting		AOI2	AOI2→AOI3→AOI2
B5	06:10		I set the slowest one	AOI2→AOI5→AOI2	AOI2→AOI5→AOI3
B6	06:11	Then I set the fastest one		AOI2	AOI3

Furthermore, the discourse E1–E6 display another problem, that is attention misunderstanding. However, from E1–E6, it can be found that STUDENT A is talking about the cumulative rainfall of AOI6 while STUDENT B was not sure which AOI to observe and transited among different AOIs. Thus, it reveals that the two students encounter misunderstanding in their visual attention and thus cause ineffective collaboration.

STUDENT B



STUDENT A

Timeline : X*50/1000/60(minute)

Fig. 3. Introduction to the Cross-Recurrence Plot cooperation status of the pair B.

This study found that the two pairs demonstrated different patterns of collaboration. It can be inferred by the CRP that pair A demonstrated more marked blocks in the activity than pair B did. The dialogue data also demonstrate that pair A members will inform each other of the operation status and thus demonstrated better joint attention. On the contrary, pair B lacked coordination and cause misunderstanding in both of the process and attention. Such a difference can be also shown in their feedback to the TWQ (See Table 3) indicating that pair A perceived a higher level of collaboration quality than pair B did.

Table 2. Partial dialogue during the experiment and AOI conversion of the pair B.

Number	Timeline (min)	STUDENT A	STUDENT B	AOI_ STUDENT A	AOI_ STUDENT B
C1	03:13		Well, so are we going to make this problem now?	AOI4→AOI5→AOI7	AOI1→AOI7→AOI2
C2	03:19	Well, should we discuss it? Then press End		AOI7→AOI5→AOI7	AOI2
C3	03:25		Do we run this simulation? Or do we have to answer the question on the right side?	AOI5→AOI2→ AOI5→AOI7→ AOI5→AOI2→AOI7	AOI2→AOI1→ AOI7→AOI1→ AOI7→AOI2→AOI3

(*continued*)

Table 2. (*continued*)

Number	Timeline (min)	STUDENT A	STUDENT B	AOI_ STUDENT A	AOI_ STUDENT B
⋮					
D1	04:20	Then we are end?		AOI6	AOI2
D2	04:22		Do you want to run the simulation? From speed 2, the rainfall density is fixed, and adjust to the speed is 4, I press run	AOI6→AOI5→AOI4→AOI5→AOI6→AOI2→AOI3→AOI7→AOI2→AOI5→AOI6→AOI2→AOI4	AOI2→AOI1→AOI2→AOI4→AOI2→AOI5→AOI6→AOI3→AOI2→AOI4→AOI5→AOI3→AOI2
D3	04:58		I do reset	AOI2	AOI2→AOI5→AOI2
D4	05:00	Well… in fact, your numbers will not affect my data		AOI4	AOI2→AOI5→AOI6→AOI2
⋮					
E-1	06:50	So, the shorter your time, the faster your speed, and the more rainfall there will be		AOI6	AOI3→AOI2→AOI6→AOI3
E-2	06:59		The less rainfall there will be	AOI6	AOI3
E-3	07:02	The more rainfall there will be		AOI6	AOI3
E-4	07:05	It will be…		AOI6	AOI3
E-5	07:07		Wait, so who is the rainfall?	AOI6	AOI3
E-6	07:11	It is the relatively large amount of rainfall		AOI6	AOI3→AOI2→AOI5

Table 3. Two pairs of cooperation quality.

	Pair A	Pair B
Communication	4.125	2.875
Coordination	3.875	2.875
Balance of member contributions	4.75	3.5
Support	4.167	2.75
Effort	4.375	3.125

4 Conclusion

In the case study above, the marked blocks on the diagonal of the CRP display the degree to which two individually jointly pay attention to the same AOI together. In the two pairs of this study, pair A demonstrated higher quality of collaboration than the pair B did. Through the dual eye-tracking technique, we also identified three main problems when the computer simulations are used to support online synchronous collaborative learning, that is, the problem of lacking coordination, the process misunderstanding problem, and misunderstanding in partners' attention. It is worthwhile to investigate what mechanism is helpful to amend these problems. For instance, collaborative simulations which enforce the synchronization of all operations to the simulation of all participants may be helpful to guide students to jointly attend to the shared focus. Furthermore, this study triangulated students discourse records with visual attention through eye-tracking techniques. It is found that such approach help the researcher gain more insight on the detail process of the collaboration. Researchers may find such an approach helpful to look into the constraints and affordances of other new collaborative learning systems.

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