# Examining an Online Collaboration Learning Environment with the Dual Eye-Tracking Paradigm: The Case of Virtual Math Teams

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**Abstract.** The aim of this study is to investigate the computer supported collaborative problem solving processes using the dual eye-tracking method. 18 university students participated in this study, and 9 pairs tried to solve 10 geometry problems using Virtual Math Team (VMT) online environment. Which situations the participants' eye movements, and eye gazes overlap, and how usability of VMT environment affect the problem solving processes are tried to identify. After experiments with two eye-trackers, a questionnaire including System Usability Scale and open-ended questions was filled by participants. Eye-tracker data were analyzed both quantitatively using cross-recurrence analysis, and qualitatively using interaction analysis. Analysis of eye-tracker data and open-ended questions are consistent, and support to each other. Results show that pairs collaborating with higher level have more gazes overlapping, more shared understanding, and anticipatory gazes than pairs having with low level. Also, usability of the system and awareness tools affect the collaboration processes.

**Keywords:** computer supported collaborative learning, collaborative problem solving, joint attention, gaze overlap, dual eye tracking.

## 1 Introduction

People around the world can communicate with each other with the developments of Information and Communication Technology (ICT). Particularly young people have shown great interest to ICT based communication tools like instant messaging, chat and social networking sites (Lenhart et al., 2007). This allows various peer groups to build knowledge together and further their understanding by engaging in collective discussions online. As a research paradigm that has attracted increasing interest within Instructional Technology, Computer-Supported Collaborative Learning (CSCL) specifically focuses on how ICT technologies can be designed and used to better support collective meaning-making practices of learners (Stahl, Koschmann & Suthers, 2006).

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The design of effective awareness mechanisms is a fundamental usability concern in CSCL research since such features enable learners to monitor and coordinate each other's' actions as they gradually achieve a sense of joint attention, which is considered as a prerequisite for productive collaboration (Barron, 2003). Achievement of joint attention is particularly challenging when learners are engaged with multiple interaction spaces where they can exchange not only text messages but also shared drawings (Cakir, Zemel & Stahl, 2009). Most CSCL systems aim to help users monitor each other's actions by providing annotation features, color-coded text, referencing tools; system generated messages that display who is currently typing/drawing or present in the environment as well as visualizations that mirror the state of ongoing collaboration (Soller et al., 2003).

The influence of such features on collaboration is often assessed via outcome measures or discourse analysis of interaction logs. Outcome measures are important for making an overall assessment of the effectiveness of collaboration, but they provide an indirect assessment of the influence of designed interactive features on the collaboration process (Dillenbourg et al., 1995). Discourse analysis of logs partly addresses this issue by focusing on the sequential organization of exchanged messages/drawings, but it requires analysts to make inferences regarding how the message production process might have been influenced by interface features based on what is said or done. In particular, when there is no explicit response or uptake, it is ambiguous whether a message or a drawing action had actually succeeded in eliciting the attention of other members. Analysis of such cases are important as they may point to serious usability issues, and this kind of analysis requires further information regarding where participants allocate their attention while they produce their own messages and monitor those of others.

The aim of this study is to investigate joint eye gaze features for assessing the collaboration processes and evaluating Virtual Math Team (VMT), (Stahl, 2009; Stahl, Mantoan & Weimar, 2013), which is a CSCL environment designed to support collaborative math problem-solving activities online by providing a text-based chat tool together with a shared drawing area with GeoGebra based dynamic geometry features, using dual eye-tracking paradigm. Dual eye-tracking is a promising technique to investigate the collaboration and interaction processes among two people. There are two eye-trackers recording the eye movements of two people working together.

In this study, some important uses of dual eye-tracking method are presented such as the collaboration level between pairs, and difficulties that pairs face during collaborative problem solving processes. This kind of methods provides researchers with not only assessment of collaborative problem solving processes, but also guidance for usability studies to improve CSCL environments in terms of ease of use. Designing automated support for the assessment of collaborative learning is becoming an important need given the recent interest towards collaborative learning pedagogy and systems that support such activities. PISA exam will, also, include questions evaluating collaboration skills (OECD, 2013). So there is an important need for designing useful and effective collaborative environments, and assessing them in order to support the collaborative learning pedagogy and systems. Some of the measures searched in this study can be improved to meet the need for large scale applications, evaluate them, and developing advanced awareness features to help learners to develop coordination skills necessary to work together as a team.

Research questions are presented below;

1. To what extent VMT's features facilitate joint attention? When and where gaze overlaps occur?
2. Is there a relationship between the amount of gaze overlap and success in joint problem solving and collaboration?
3. How does the usability of VMT environment affect collaborative problem solving processes?

   The aim of this study is to identify in which situations participants' gaze patterns overlap, and how the percentage of this overlap correlate with the degree of attention paid to awareness features and with the overall success of the collaborative problem solving process.

## 2 Method

18 students (9 pairs) from the Middle East Technical University (METU) were recruited for this study. While forming the pairs, some criteria were considered such as they know each other, and both of them are from the same department, and same educational level. The reason why these criteria were used is that, the more partners know their level of knowledge, the more interaction between pair increases, because this awareness provides partners with better understanding among them (Nüssli, 2011). In addition to this, according to Sangin (2009), since partners have awareness about their knowledge, they have better estimation about their actions. Because this study focuses on technological factors on joint work, these kinds of pairs are more appropriate to control the social factors. Each pair attempted 10 geometry problems on VMT environment. During the experiments, the eye movements of the participants were recorded with two Tobii eye-trackers. In VMT environment, there are chat rooms which provide participants with communication via chat section. For this study, chat rooms were created for each pair. In these chat rooms, there are 3 tabs: Questions, GeoGebra, and Results. Question tab includes 10 questions. GeoGebra tab consists of algebra view providing participants with monitoring the coordinates of drawings, and construction area providing participants with drawing construction. In GeoGebra tab, only one participant can take control, and draw the construction. In result tab, participants were asked to write their results on whiteboard and proof after they solve the problems. Before the solving questions part, there were a training part lasting approximately 10 minutes which explains the VMT environment, GeoGebra tools used frequently while solving geometry problems, and gives an example.

After the experiments, a questionnaire with System Usability Scale (SUS) (Brooke, 1986) open-ended questions was filled to obtain participants' comments about the collaboration process and the online environment features, so mixed method research design is used for this study.

### 2.1 Data Analysis

Eye-tracker data were analyzed both quantitatively and qualitatively. The cross-recurrence analysis method (Richardson & Dale, 2005; Richardson et al., 2007) was used for the quantitative analysis of eye gaze data. Interaction analysis method was used to qualitatively examine the synchronized video recordings of sessions to explore interactional and design factors that facilitate joint attention.

For the qualitative analysis eye-tracker data were used in order to measure the degree of gaze overlap among collaborating pairs. Recording time stamps, local time stamps, coordination of gaze points and area of interests (AOI) of the eye movements were considered, and exported from Tobii Studio Software. This method is called cross-recurrence analysis, and was used in the studies of Richardson and Dale (2005) and Richardson et. al. (2007). A customize program written in Java was used for performing this analysis. The screen was divided into AOI in Tobii Software Studio. Then Java program gets the raw data extracted from Tobii Studio, and gives a scarf plot which presents the information about which AOI partners' look, when their eye gazes overlapped. After generating scarf plots for each pair, Java program produces gaze overlap distribution plot for each question of both partners with the time lag between -4000 and 4000 msec. It is formed using the total gaze overlap duration among the participants, when one participant's gaze sequence is shifted x msec where x ranges between -4000 and 4000 msec, and is incremented in 100 msec. Then, these values are converted into percentage values in accordance with the segment's length. The recurrence plot also represents the recurrence percentage distribution when the gaze sequences are randomly shuffled in order to provide a baseline for comparing against the random recurrence.

Finally, a separate and single recurrence graphs are produced for each pair containing whole session shown in recurrence analysis results part. Point 0 indicates the recurrence percentage of the pairs for exactly synchronous gaze, -200 indicates the recurrence percentage in which second participant gazes with a 200 msec delay with respect to first participant, and vice versa. The blue part represents the same info with a shuffled gaze data used as a baseline. The vertical lines are the standard error bars indicating the amount of deviation in the data for the corresponding time.

## 3 Results

### 3.1 Recurrence Analysis Results

The recurrence graphs for Pair-8 which has the best quality collaboration and for Pair-4 which has the lowest level of collaboration are presented. Each data point represents the overlap in specified time lag value while calculating the recurrence percentage. For example; there is no lag in 0 point, so both participants look at the same AOI. Then one participant's gaze data is shifted 100 msec, and gaze overlap is calculated again in order to identify the overlapping of one participant's gaze at the same area as the other participant with a 100 msec delay. Then duration is divided by segment length, and recorded -100 msec data point. Finally, for each pair, overall curve calculated using mean values of each question for 80 data points between -4000 msec and

+4000 msec. The reason why time lag value is stated between -4 and +4 seconds is that listeners' tend to look at the same location where speakers looked at a delay of 2 seconds (Richardson & Dale, 2005). In this study, communication was performed via a chat tool, so we extend the time interval to +4 and -4 seconds in order to explore gaze overlapping for the chat case. Graphs shown below are formed.

The graphs can be interpreted as:

- If the red circle line (percentage of recurrence) is far from, and has higher percentage than the blue triangle line (random baseline), it means that this pair performs high level of gaze coordination.
- If there is symmetry around the 0 point, partners follow each other's actions equivalently.
- If there is a skew on the right side of the 0 point, the participant whose eye-movement data are chosen firstly follows the second participant more. If there is a skew on the left side of the 0 point, the participant whose eye-movement data are chosen firstly is followed by the second participant more.

Fig.1 represents the recurrence percentage graph of Pair-4 which has the lowest recurrence percentage in this study. Two lines are very close to each other, intersect at some points, and recurrence percentage level is very low.

Fig. 2 shows the recurrence percentage of Pair-8 which has the highest recurrence percentage level in this study. There is symmetry around the 0 point, so we can say that both participants follow other's action at similar level. Furthermore, the distance between recurrence percentage line and random baseline increases between -2400 msec and +2800 msec, so we can say that these participants follow each other with the approximately 2 seconds time lag.

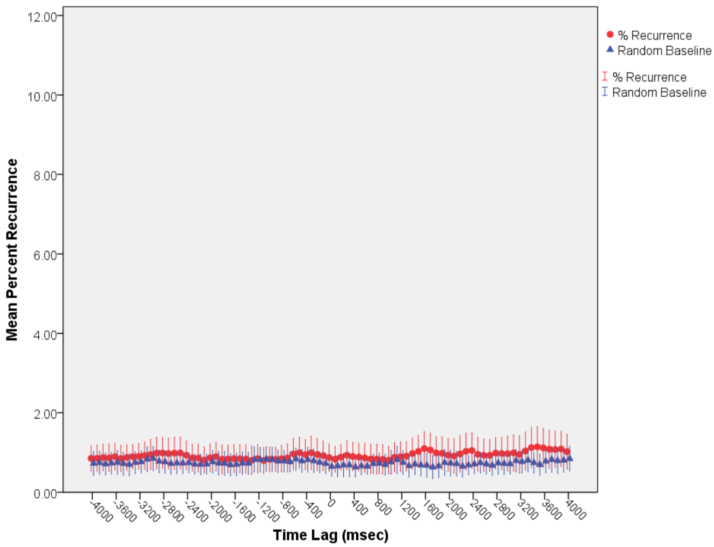


**Fig. 1.** Recurrence percentage graph of Pair-4

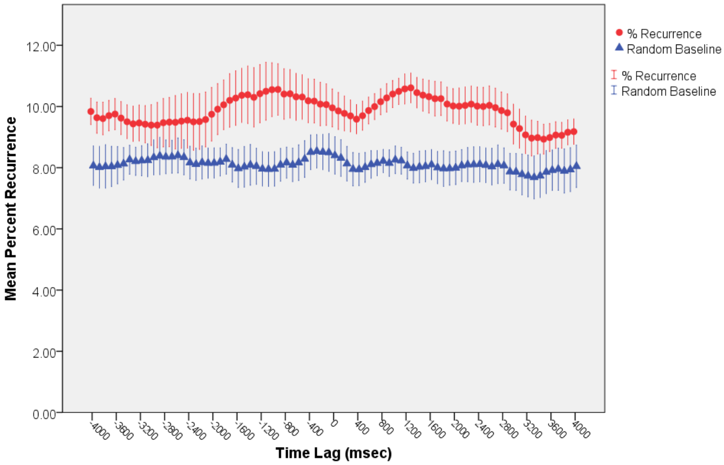


**Fig. 2.** Recurrence percentage of Pair-8

### 3.2 Interaction Analysis Results

In this part, some excerpts are presented to show the collaboration process with anticipatory gazes, where gaze overlaid video recording indicate that some participants estimate the location of next possible action of the team member before s/he performs. Suchexamples can be considered as a strong evidence for the achievement of common ground and mutual understanding. Furthermore, gaze overlap, and uses of awareness tools are the evidence of good quality collaboration.

Considering the recurrence analysis, pair-8 has the highest gaze overlap, because before starting solving the problem, they reasoned together communicating via chat element. The second highest collaboration level belongs to Pair-5. While solving the

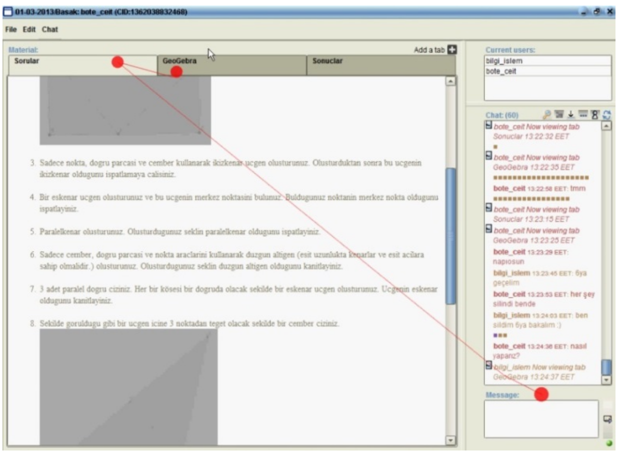


**Fig. 3.** Question-6 – Fixations of bote_ceit

problems, they used awareness messages such as following "… is typing" messages, and "Now viewing tab GeoGebra" messages which shows the one participant's tab changes on chat element. In addition to these awareness messages, VMT has awareness elements at the bottom of the screen; one represents the last usage tool, and the other one represents who has control. These two pairs used these awareness elements and messages to follow partner's actions.

In question-6 (Pair-8), both of the participants read the question. Then bilgi_islem viewed GeGebra tab, bote_ceit saw this action, and he viewed GeoGebra tab, too (see Fig. 3), so he followed his partner's action.

In question-4 (Pair-8), bote_ceit took control, and drew an equilateral triangle using equilateral polygon tool. Then he stated the midpoints of all edges (see Fig. 4). Meanwhile, bilgi_islem saw the tool that bote_ceit used, and looked at the midpoints' of the edges (see Fig. 5).

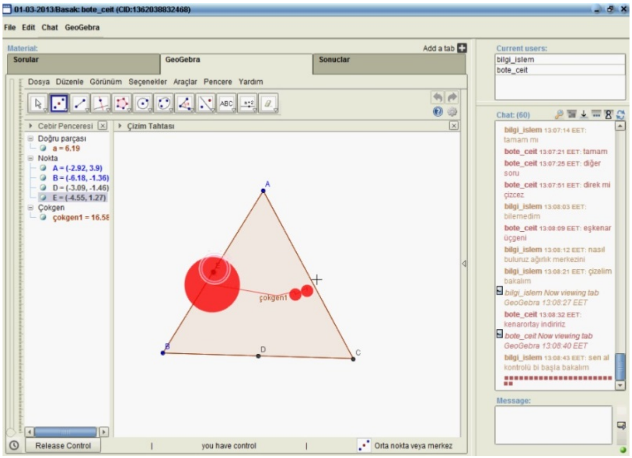


**Fig. 4.** Question-4 – Fixations of bote_ceit

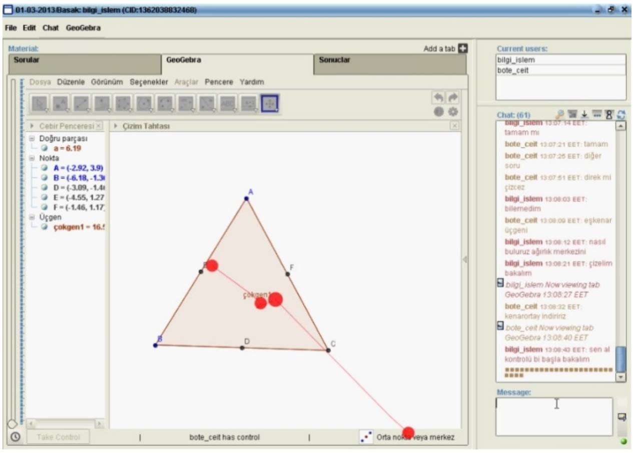


**Fig. 5.** Question-4 – Fixations of bilgi_islem

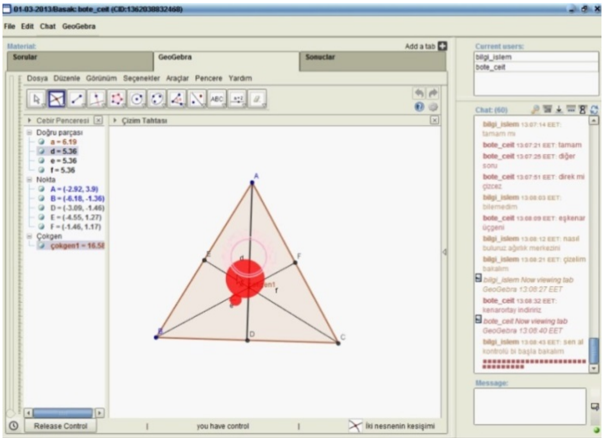

**Fig. 6.** Question-4 – Fixations of bote_ceit

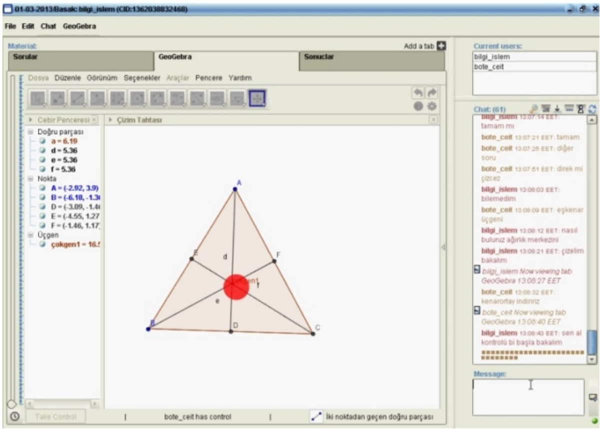

**Fig. 7.** Question-4 – Fixations of bilgi_islem

In question-4 (Pair-8), before bote_ceit stated the center point (G) (see Fig. 6), bilgi_islem anticipated this action, and looked at this location (see Fig. 7).

There are, also, some cases where there was no gaze coordination. Pair-4 has the lowest gaze occurrence. The main reason is that while one partner was writing the answers on the Results tab, the other worked on the next question, so partners could not follow their actions because they were working different tabs. The other reason is that while bilgi_islem was solving the problem, she did not look at the chat section, and could not see what her partner wrote. So gaze overlapping either did not occur in those cases or occurred by chance.

To sum up, our aim is to support the results of cross recurrence analysis by closely analyzing gaze patterns of pairs.

### 3.3 Open-Ended Questions and System Usability Scale Results

SUS score of VMT environment is 52,30 out of 100, but this result does not give detail information about the usability of VMT and collaboration process, because it is designed for evaluating the single user interface.

Answers of open-ended questions were examined to understand the participants' experiences, difficulties they faced, their ideas, and suggestions about VMT. Participants stated that chat section is the main element of collaboration process. If someone fails to solve the problem, the other one takes the control, and continues to solve problem. They, also, direct, and help each other during the process, but chat element has some difficulties. For example; communication occurred text-based, so it causes time loss, and sometimes misunderstanding may occur. Participants suggested that communication should be provided via video-based channel. In addition to these, pairs missed the partner's messages. Some participants suggested that when a chat message is sent, it should be a notification voice, so the messages attract attention of other participant.

The colors of the text messages are different for each person, but because the colors are similar, text messages are hard to follow, and read. On the other hand, some participants stated that "Now viewing tab GeoGebra" awareness message is useful to follow their partners. Furthermore, take control button is useful, because just one person constructs drawings, and confliction is prevented. This button is, also, useful for awareness among partners. The other main problem is that participants had difficulties about usage of GeoGebra tools. Participants stated that GeoGebra tools should be more easy to use. Finally, some of the participants stated that the construction area was slide, and the partner's actions were not seen.

## 4 Discussion and Conclusion

In this part, results are discussed according to research questions. For the first research question, it is observed that some VMT features provide coordination of joint attention to the users. Chat tool is one of these tools, participants used it for communication, and they directed each other while solving the problems. For example, "... is typing" awareness feature help participants with facilitating joint attention, because when one was constructing the solution, the other wrote messages, and suggest solution, or asked something. In addition to this, when a participant changes the tab, "... view ... tab" awareness message is seen. It, also, provides users with joint attention, because when one sees this tab changes, s/he changes tab, too, and follows his/her partner. Furthermore, construction area on GeoGebra tab makes the on-going construction visible to all users. Eye-tracking videos show us these gazes and joint attention. Thus, gaze overlapping especially occur on construction area, and chat tool by using awareness messages.

For the second research question, results of the recurrence analysis and interaction analysis show that there is relationship between the amount of gaze overlap and success in joint problem solving and collaboration. This finding is consistent with the literature, and reported by some other studies that high-quality collaboration is related with high level gaze recurrence (Jermann, Nüssli, Mullins & Dillenbourg, 2011; Richardson & Dale, 2005; Jermann & Nüssli, 2012). Pairs having high quality of collaboration show more gaze overlap than the pair having low quality of collaboration, because good pairs usually followed partner's action, reasoned together, suggested solutions to each other. But pairs with low quality of collaboration just divided the work as constructing solution and writing solution, and did their sub-work, so they work cooperatively, not collaboratively. As Dillenbourg (1999a) stated that they worked cooperatively, because they divided the whole work into sub-work, work individually and finally united the final work.

For the third research question, open-ended question results are used. Participants stated that they faced with some difficulties, because of the some VMT features. Some participants said that it was difficult to follow construction area and chat area simultaneously. There are some reasons of this difficulty. For example, colors of each user's messages are different, but very similar, so participants faced difficulty in identifying which messages belongs to whom, and they had to read last few messages. This difficulty slows down the communication process. Because color selection is an important factor affecting users' perception, interface should be designed according to design principles. The other reason about difficulty is about awareness messages about changing tab action and their crowded view. Although this awareness messages support collaboration, and following the partner's action, the design of them is not suitable, because color tone is similar to participants' message, and people see their own changing tab action. It is not necessary. Another reason of difficulty is about the construction area. When a user zooms in, zooms out or moves the construction area, other user cannot see these actions, so "what you see is what I see" design principle for collaborative systems fails. This usability problem affects the collaboration process.

Because there is a big problem about understanding users' motivation regarding to using collaborative environment (Holtzblatt, Damianos & Weiss, 2010; Matthews, Whittaker, Moran, Yuen & Judge, 2011), users' experiences and their feedback about the environment should be considered well, and reflected to the design of user interface. Because SUS is designed for single user interface usability evaluation, it is inadequate to assess the usability of collaborative environment. Although there are some rating schemes for assessing the quality of collaborative environment such as developed by Meier, Spada and Rummel (2007), there is a big need to develop scale for evaluating usability of collaborative environment.

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